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STUDENT REPORT

SPACE, WARGAMES AND DISPLAYS

MAJOR RICHARD J. WENDT, USAF 87-2695

"insights into tomorrow"

87

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There is a need to enhance the introduction of space systems into the professional military education (PME) system of the Air Force. This study recommends what to incorporate; how to incorporate it; and in particular, how to display it. Displays can help students understand the three dimensional aspects of space activities. Wargames acquaint the students with both the capabilities and limitations of space systems; and wargames can illustrate how much we depend on space systems for the conduct of war on earth. War in space may be on the horizon, and new simulation tools are needed to study the doctrines and strategies required to meet the challenge. This study analyzes the needs of three different audiences in the PME environment; and recommends an approach for the development of wargames and simulation tools for each with an emphasis on displays.

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PREFACE

This staff analysis examines ways of enhancing the study of space systems in the professional military education (PME) system of the Air Force. Military space activities are reviewed; educational and wargaming requirements are examined; and displays are recommended to improve the students' awareness of space systems' capabilities and limitations. Displays help students understand the three-dimensional aspects of space activities. Wargames can illustrate how much we depend on space systems for the conduct of war here on earth. War in space may be on the horizon, and new simulation tools are needed to study the doctrines and strategies required to meet the challenge. This study analyzes the needs of three different audiences in the PME environment and recommends an approach for the development of wargames and simulation tools for each audience, with an emphasis on displays.

The author would like to acknowledge the help of many who contributed ideas and comments to the analysis. Lt Col Barry Britton, the faculty advisor, was most helpful and patient with his advice. Col Ted Schroeder, the project sponsor, and the Space Command representative to the Air War College (AWC), was most encouraging and helpful. Special thanks are due to Maj Larry Roseland who, along with Lt Col Britton, conducted a Space Wargaming elective course at ACSC in the Fall of 1986. Much of the material for this paper is based on that course. In the same vein, those ACSC and AWC students who are also working on the space wargaming project contributed ideas and suggestions. Majors Luis D'Gornaz, Hal Hagemeir, Michael Mantz, and Bruce Thieman; along with Lt Cols Spike Robinson, Vic Tambone, and John Vloet helped immensely. Other members of the elective course including Majors Erik Anderson, David Meer and Kirk Hunter had a major impact as well. The guest lecturers of the elective course including Dr. Joseph Strange of the AWC, Lt Col William Hudson of the Air Force Wargaming Center, and Col Charles Heimach from Air Force Space Command provided needed assistance. Special thanks go to Capt Don Jenkins of the Wargaming Center for his suggestions, and to fellow student Maj Al Glock for his help with the computer generated background displays. The major contribution of Mr. Dan Bryce of the Aerospace Corporation, El Segundo, California, must be acknowledged for his work on the development of the Satellite Orbit Analysis Package (SOAP) which forms the foundation for the recommended displays. Finally, the author thanks Mrs. Karen Rotach whose flawless work in the preparation of the report was superb.

CONTINUED

This report is intended for use by the ACSC and AWC curriculum developers to assist them in the use of space-related displays. The report is also meant for the Air Force Wargaming Center. It provides a roadmap for the incorporation of space capabilities into the new Command Readiness Exercise System at the Wargaming Center as the development schedule permits. Finally, a simulation tool is recommended for use when conducting strategy and doctrine research. This same tool, when used with a manual space game next year by the ACSC and AWC students, can provide the basis for a computerized space wargame.

ABOUT THE AUTHOR

Major Richard J. Wendt has held a number of space-related assignments in the U.S. Air Force. In 1969, Major Wendt received his Bachelor of Science degree in Mathematics from St. Francis College, Brooklyn, New York. He was awarded the Master of Science degree in Mathematics in 1971 from Rensselaer Polytechnic Institute, Troy, New York. He entered the Air Force in 1972 from the Reserve Officer Training Corps; and his initial duties involved satellite operations at the then Sunnyvale Air Force Station, Sunnyvale, California. Subsequent assignments have included: space tracking and missile warning duties at Thule AB, Greenland; computer program development at Space Division, Los Angeles AFS, California; and space operations staff duties at the Pentagon, Washington, D.C. While at Space Division, Major Wendt worked on a simulation system designed to introduce tactical forces to the capabilities and limitations of space systems. Prior to attending the Air Command and Staff College, Major Wendt directed the mission planning for a satellite program at the now Onizuka Air Force Station, Sunnyvale, California. He is married to the former Mary Frances [redacted] of Joliet, Illinois. They have a son, Robert.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLES

FIGURES

==========================CONTINUED==========================

EXECUTIVE SUMMARY

REPORT NUMBER 87-2695

AUTHOR(S) MAJOR RICHARD J. WENDT, USAF

TITLE SPACE, WARGAMES AND DISPLAYS

I. Purpose: To assist the introduction of space capabilities into Air University wargames and curricula by recommending what to incorporate; how to incorporate it; and in particular, how to display it.

II. Problem: Air University is developing a new wargaming system at the Air Force Wargaming Center (AFWC), and the AFWC plans to incorporate space systems in an upcoming phase of the development. This study analyzes the audiences at Air University for displays of space systems. Additional capabilities and displays are needed for both curriculum and wargaming requirements.

III. Data: Space is a relatively new and different arena for military activities. Space capabilities, doctrines and strategies are in their infancy, and all are growing in importance and changing rapidly. Teaching students at the Air Command and Staff College (ACSC) and the Air War College (AWC) the fundamentals of space operations is a challenge because of the differences between the familiar air operations and the unfamiliar space environment. Displays can help students understand the three-dimensional aspects of space activities. Military satellites support terrestrial forces by gathering information. Wargames can acquaint the students with both the capabilities and limitations of space systems; and wargames can illustrate how much we depend on space systems for the conduct of war on earth. There are many different types of wargames for use in integrating space activities into the educational experience

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at ACSC and the AWC. For the general audience of students, space can be added to the currently planned games of the Command Readiness Exercise System (CRES) at the AFWC. War in space may be on the horizon either because of our dependence on space-based weapons systems in the Strategic Defense Initiative, or the need to defend our current space assets.

IV. Conclusions: New simulation tools and wargames are needed to study the doctrines and strategies required to meet the challenge. Improvements in computer graphics and displays give students, the faculty, and researchers the opportunity to efficiently research new strategic concepts. Simulation tools and displays, manual space wargames, and possibly a computerized space wargame will help both students and researchers explore new strategies and doctrines.

V. Recommendations: Space-related displays can help in both an educational and analytical context. Three steps are proposed to improve the use of space-related displays at Air University. First, it is recommended that a project be created, or software obtained, to view basic scenes related to space on the personal computers available in both the Wargaming Center and each seminar room. The figures of this report are recommended for use as the basic scenes. Second, eleven areas for satellite modelling in the planned wargames are recommended along with their associated displays. Third, Air University should obtain a copy of a display system developed for the Air Force's Space Division. This powerful interactive graphics display system for simulating orbits will assist researchers at Air University. The researchers will use this display system to develop strategies, doctrines, and a space wargame.

Chapter One

INTRODUCTION

OVERVIEW

Space capabilities are not often considered when the Air Force develops wargames. A RAND wargaming analyst interviewing 21 defense officials in the spring of 1983 found that none had ever seen space meaningfully played in a wargame despite the importance of the topic in their minds (64:4). Space systems are often considered exotic. The systems themselves are complicated, their military usefulness not well known, and thus they are often not considered when wargames are developed for either the Intermediate or the Senior Service Schools. Current wargames at Air University do not model space systems. The Air Force has recently established an Air Force Wargaming Center at Maxwell AFB, Alabama; and the Center is creating a new wargaming system. Although space capabilities will not be delivered in the early phases of the new wargaming center, some space assets will be modelled in a later phase (24:8-9).

The Air Force's long-term objective is to advance the study of space within its professional military education system as well as to enhance the knowledge of space systems for all Air Force personnel (56:8-7). The Air Force's plans to incorporate space systems into its wargaming system are still evolving. As the Air Force role in space grows, it needs to expand its capabilities to teach space systems in its professional military education program. This paper is designed to assist the introduction of space capabilities into Air University wargames by recommending what to incorporate; how to incorporate it; and in particular, how to display it.

This staff analysis has three goals: first, to examine current and future space warfighting capabilities; second, to determine whether, how, and which wargames may enhance our knowledge of space systems and space warfare; and third, to develop candidate displays for near-term use at Air University. To understand what is to be gamed in a space wargame it is necessary to first review our limited capabilities in space. The analysis will answer the questions: what are the important characteristics of the space environment? What are we doing militarily in space? What are our plans for the future? What are our strategies and doctrines for the employment of space systems? Having explored some important topics related to space, the study will next analyze wargames. What are the unique characteristics of a good wargame? The emphasis here will be three-pronged: first, the essential elements of a successful wargame will be reviewed; second, the new wargaming system for the Air Force Wargaming Center will be described; and third, the requirements for a space wargame will be presented. As will be shown later, before one can recommend changes to existing simulations or the creation of new ones, one must clearly determine the learning objectives. The analysis will start with the space phase learning objectives at the Air Command and Staff College. The learning objectives will be examined to identify information and display requirements. The proposed displays are intended for use at the Air Command and Staff College (ACSC), the Air War College (AWC), or the Air Force Wargaming Center.

Space assets when incorporated into educational or special wargames can teach military personnel how much they depend upon those systems for success, and how these systems can affect conflict (38:25). Wargames can be used as both an educational and an analytical tool (38:22). Wargames can give the students important qualitative insights into warfighting trends (62:10). As we depend more and more on space as an operating medium, it becomes more and more important to protect our assets there through space operations and space deterrence (28:41; 55:9). Specialized wargames which simulate the possibilities of conflict in space will provide the serious student of future wars an insight into workable doctrines and strategies (1:6-8). The ability of wargames to explore future strategies and doctrines is especially important for space systems. Strategies and doctrines for space defense and future space engagements are constrained by both the dearth of practical experience and the tremendous costs involved with exercising such capabilities (84:156; 64:5). A space wargame could model uncertainty which is likely to abound in any future space engagements as will be described later. One of the many products of such a wargame could be risk analyses of space strategies, i.e. one could test current or proposed strategies to determine the shortfall between that which is required and that which is possible (48:18). The need for an analytic tool to study space operations, as well as the requirement to educate Air Force personnel on space, calls for a multi-faceted approach. Before analyzing the approach in Chapters 2, 3 and 4 of this report, the assumptions and limitations of the study will be described.

ASSUMPTIONS AND LIMITATIONS

To limit the scope of the study, the following assumptions are made and limitations acknowledged on feasible recommendations. It is assumed that existing or near-term (ten years at most) space-based capabilities would be of interest in the war-games. Thus, some near-term SDI concepts would be modelled. Current and planned space capabilities will be of interest.

Our ability to wargame space capabilities or space scenarios will also be constrained by the current and planned wargames. As mentioned earlier, the currently used wargames at Air University will soon be replaced. It would not be prudent to make changes in these games because they will not be in use much longer (no later than 1989) (24:9). Another important requirement is the need to satisfy specific learning objectives (96:--). One must avoid the situation where space modelling unrealistically skews the results and learning objectives of a wargame whose main purpose is unrelated to space. The planned Command Readiness Exercise System (CRES) for the Air Force Wargaming Center provides the basis for comparison of space-related wargaming needs. Space-related learning objectives will be compared to this baseline system. Given the fact that CRES is under development, recommendations made will attempt to minimize the impact on planned Air University wargames and display devices.

In recognition of the fact that different learning objectives apply to different students, three audiences, or classes of students are considered in this study (94:--). The first class is the average students of ACSC and AWC. As part of their education at the school, they will be exposed to certain fundamentals of space operations within the curricula of the two schools. This study will look at displays which will enhance that curricula. The second group of students may include the first group, it consists of those students who are involved in the various wargames employed throughout the school year. These games are being developed now, and some are very similar to wargames currently used. The planned games will be examined to see how the student wargamer could be provided with new information on the utility and limits of space systems in the wargames. It is assumed that space will not apply to every wargame; and since each of these wargames has a larger educational objective, space play will be limited to a carefully selected set of learning objectives. The third group of students, assumed interested in space play in a wargame, includes serious students of space warfare. Their desired learning objectives are assumed to be greater in number than the other two classes of students. Once again, an attempt will be made to minimize the impact on planning improvements to the wargaming system; but unique requirements for this audience are likely to drive unique display requirements. Flexibility will be very important here so that the various displays can be expanded later as requirements grow. Near-term space capabilities, displayed to three audiences of students at Air University using the planned capabilities of Air University Schools and the Air Force Wargaming Center, highlight the assumptions made in this study.

The purpose is to assist ACSC and AWC students in achieving a greater understanding of space systems and their environment. The recommended displays are designed to contribute to a program plan "...specifying simulation tools and displays for evolving, required decision-making for space" (84:156). As mentioned above, a three-pronged approach is needed, but capabilities built for one audience can be used for others. The first aspect of space wargame displays to be discussed is space: the environment; its military use; the constraints on its use; and both doctrines and strategies.

Chapter Two

SPACE

Before one can postulate what should be displayed in a space-related wargame, one should understand what the military does in space. Four aspects of the military use of space will be reviewed. The author begins with a description of the space environment with an emphasis on differences between the space and terrestrial environments. Next, military missions and functions in space will be described. The technological and political constraints on the use of space will be reviewed. Finally, the study will analyze doctrines and strategies on the use of space to show where wargames may be helpful.

THE SPACE ENVIRONMENT

The space environment is both literally and figuratively a vacuum. There have been a variety of characterizations of the space environment. It has been described as "infinitely large," "a vacuum," and "subject to the law of gravity for motion" (57:260; 56:1-2). It has also been characterized as "vast," "empty," "conducive to electromagnetic radiation," "subject to large temperature differences," "strewn with meteoroids," and "subject to the laws of gravity" (67:26; 59:1-5 - 1-10).

The first reference appears to hit the essence: space is infinite, relatively empty and subject to gravity for motion. From these characterizations flow various attempts to define space zones. Each definition is arbitrary and uses the Earth as the starting point for the discussions. Three zones for satellite orbits have been defined (5:6-8). Low earth orbit (LEO) is from 150 kilometers above the earth's surface to 1,500 kilometers above the earth. Medium Earth Orbits (MEO) exist from 1,500 kilometers to 35,800 kilometers (or 22,300 nautical miles: the geostationary altitude) above the earth's surface. Finally, orbits of 35,800 kilometers in altitude and beyond are classified as high earth orbits (HEO). See Figure 1 for an illustration. There are very few vehicles that operate beyond the geosynchronous (geostationary) orbits, and there are practically no military vehicles operating at these greater ranges from the earth. The outer zone is not likely to hold military significance soon, although some believe military satellites can be hidden there (57:263; 48:20; 5:38-39). Therefore the volume of space of interest here encompasses that from the earth's surface to a few thousand nautical miles beyond geosynchronous altitude. Of about 4,600 man-made objects tracked by NORAD in January 1982, 83% were in low earth orbit (5:7). The geosynchronous belt around the earth's equator has been compared to choke points in naval parlance (57:265). Another property of space to note is that along with the motion following the laws of gravity, the speeds involved are very large (a typical LEO satellite travels at 25,700 ft/sec or 17,525 mi/hr); and more importantly, changing orbits is very difficult. It takes a great deal of propulsive power to change the flight path (57:264). Obviously, the vacuum of space is inhospitable to humans. A great deal of support is needed to operate both manned and unmanned vehicles in space (56:1-2; 3:96). These elements of the environment will be a necessary part of the learning objectives to be discussed later.

MILITARY USE

The military operates in space because of some unique advantages of being there. Space is the new "high ground," and surveillance and reconnaissance spacecraft are following the pattern of the balloon in the Civil War and the airplane in World War I (13:52; 15:17). Most satellites today collect information in one form or another (40:7). The availability of this information to terrestrial users depends upon the satellite's orbit, which is determined by the orbital parameters selected at launch. Whether space systems are surveilling the Soviet Union to warn of an ICBM attack (19:47) or providing 70-80% of the US long haul military communications (8:28), satellites are used because their position in space and their ability to observe the earth enable them to do something uniquely or more efficiently (55:5). The price one pays for gaining these advantages is a change in operating characteristics. Whereas air forces have the inherent characteristics of range, speed and flexibility (maneuverability) (54:2-2); space forces have the characteristics of altitude (above the earth's surface), speed (within very narrow constraints) (25:19) and pointability (77:vii). Pointability is the ability of a satellite to look in one direction while travelling in another direction. As mentioned earlier, the altitudes required to obtain orbital velocity mean that spacecraft can occupy higher ground than possible with aircraft. But speed and position at later times can be accurately predicted if known once (77:21). Directed energy weapons can propagate tremendous distances through the vacuum of space; perfection of these weapons, to include their sophisticated pointing systems, would provide an unprecedented capability for concentrating destructive force (77:31; 25:21). This latter capability is a hallmark of SDI schemes for effective ballistic missile defense (57:265). As we depend more on space assets for essential military functions, we provide an almost irresistible target in space for the Soviets

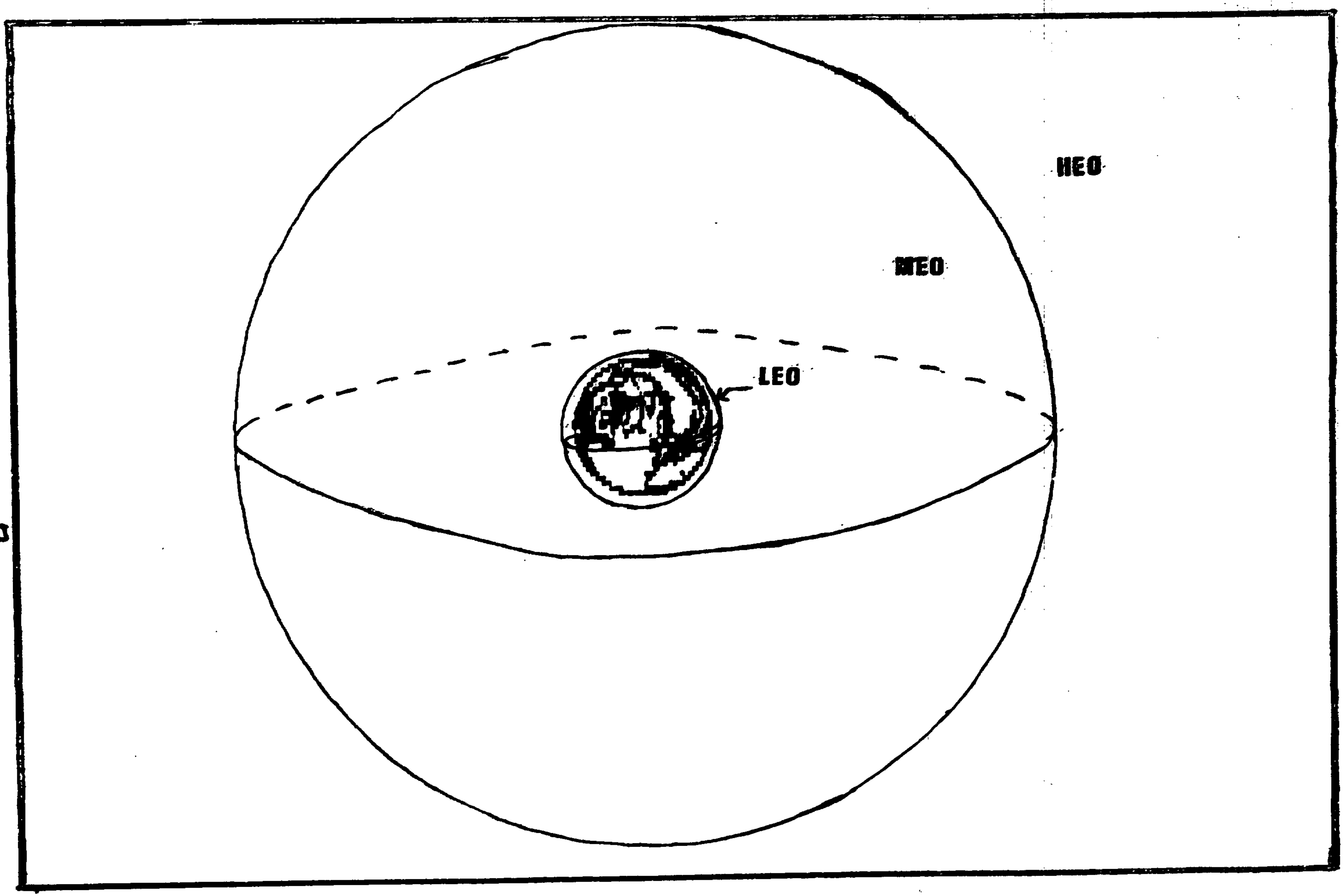

Figure 1 — SPACE ZONES

(43:53; 31:74; 19:50). Their response is twofold: the development of strategic and space weaponry while simultaneously trying to control an American response through arms negotiations (34:47). Their commitment to BMD-related research is massive (53:43-49; 27:8-13). Suffice it to say that both the US and the USSR see advantages to operating in space as described above. These advantages will be more apparent when we discuss the functions and missions performed in space.

The Air Force's Space Plan (56:4-1) defines the following broad functions and specific missions in space. Militarily one performs support missions or combat missions in space. Under the support mission are the two broad functions of force enhancement and space support. The combat mission includes the two broad categories of space control and force application. Figure 2 depicts the various functions and missions (58:38-41; 56:4-1; 55:8-9; 57:266-268; 19:45). The next few paragraphs will describe these functions and missions indicating future trends for possible wargaming consideration.

Force enhancement supports terrestrial military forces, and almost all American and Soviet military space assets are assigned these missions (19:45-46; 41:14-16) of communications, navigation, reconnaissance, surveillance or environmental monitoring (weather, geodesy, etc.). Communications satellites and surveillance satellites typically occupy HEO's; navigation satellites are planned for MEO's while reconnaissance and environmental satellites occupy LEO's. As mentioned earlier, satellites perform these force enhancement missions because of the unique advantages space provides, or because it is more efficient to do these from space (39:38-39). These systems are continuously being upgraded and modified. New systems are constantly under consideration such as one for air and ocean area surveillance (36:37; 23:94). This activity attests to the permanence of these systems. However, they are not without some inherent problems. "The military satellites that both (US and USSR) sides have fielded are essentially `peacetime` systems and are vulnerable to destruction in case of war" (40:7). For cost reasons, the US has sought to achieve maximum on-orbit longevity via design of high reliability subsystems (70:11); but long life must be weighed against the satellite's inaccessibility for modification (57:262). These systems are being improved to provide better functional support to terrestrial forces and decision-makers (20:68); and their survivability, reliability, endurability and accessibility will likely be improved as feasible (55:6; 70:11). These latter considerations are important because "when we go to war, we will need to fight a war here on earth using whatever orbital assets that are already in orbit" (33:18). Since these are the primary military satellites for terrestrial military support, they will be the ones of main interest for injection into AU wargames (88:--).

Space support consists of launch operations and on-orbit control. Some references cite orbit transfer operations and recovery of payload data as additional missions (56:4-1), but

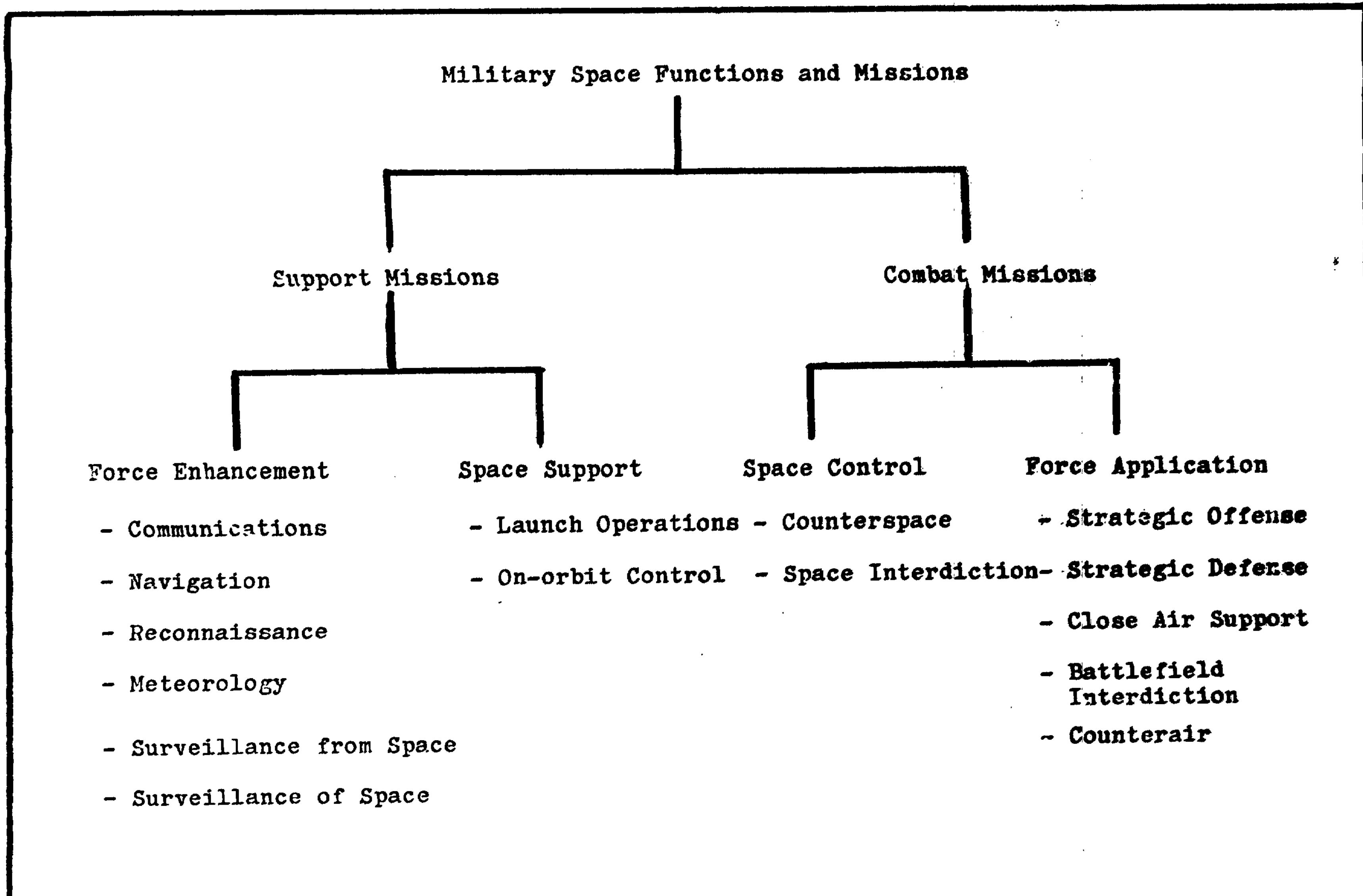

Figure 2 — MILITARY SPACE FUNCTIONS AND MISSIONS

here they are included in on-orbit control. Launch operations are those activities necessary to achieve orbit. On-orbit control provides for the caretaking and use of the satellites once they are in orbit. This will typically consist of mission planning, mission control, and tracking of the satellite. It may also include retrieval of data from the vehicle and performance evaluation of spacecraft subsystems (3:96). Improvements are planned for US launch capabilities following recent difficulties (21:5; 46:4). On-orbit operations have been modernized from time to time, but many of the activities are essentially unchanged from the beginning of spaceflight. These missions would not usually be of interest in a wargame, although launch trajectories and capabilities of new propulsion systems (44:30-31) would probably be the exceptions and therefore of interest.

The goal of space control is to protect the US use of space while denying unimpeded enemy use of space (55:5,8; 58:38; 39:41). Space control is different from control in the classical sense. It is not "conquest of space," but rather local control of some space over some period of time (88:--). Space control is different because: first, you are "always passing by your enemy" (88:--); second, there is no clear demarcation between forces; and third, identification of a satellite's function is hard and/or time-consuming (88:--). Our ability to achieve any measurable space control is very limited. Only anti-satellite weapons systems and passive survivability measures (20:69; 8:11) contribute to space control today; but these are important because of the threat. The threat could come from attack on US satellites in LEO by Soviet ASAT's or lasers, attacks on our ground support assets, or through electronic interference with the satellites or associated communications links (8:45-46; 34:43). The US anti-satellite system is launched from earth to interdict enemy satellites (15:18), but conceivably one could counter space assets from space itself. Some rudimentary ASAT input to wargames may be useful, but the majority of the space control missions would be of interest only to the serious student of space warfare to investigate future concepts.

Force application is the projection of weapons systems capabilities onto the terrestrial battlefield from space without using weapons of mass destruction (58:38; 55:8). Neither the US nor the USSR has a demonstrated capability to do this. The missions listed in Figure 2 are the potential ones that could be accomplished. They are the space counterparts of air missions (54:3-2 - 3-4; 57:266-268). The only US proposed capability in this area could occur through the SDI. SDI may or may not require space-based weapons components for boost and mid-phase intercept in conjunction with a terrestrial-based terminal defense (40:12). Any space-based weapons assets would fall into the force application function. The SDI Office is studying the possible use of lasers (optical or X-ray), particle beam weapons (neutral hydrogen beams), or kinetic energy weapons for ballistic missile defense (17:60). The first two possibilities, called directed energy weapons, use the emptiness of space to take advantage of the unhindered propagation there; but to perform boost phase intercept of ICBM's, they must penetrate the earth's atmosphere. The laser itself need not be in space. Concepts employing a free electron laser on the ground with mirrors in space are being highlighted now by the SDI Office (14:32). Some feel that if such a system is deployed, survivability would be difficult (18:67) and would require additional measures to defend the space segment (31:74). The point is that SDI configurations are in the research phase and changing rapidly. As these concepts evolve and a preferred system is proposed, the concepts would be of interest to serious students of space warfare to study strategies for employment. This might also be the gist of a space-only wargame. "Clearly, the issue over military space objectives has not been resolved" (25:18).

CONSTRAINTS

Military space capabilities like all military forces are developed, deployed and employed under both political and technical constraints. Political constraints include legal constraints, fiscal constraints, etc., while technical constraints include engineering limits on our ability to get into space. This first group of constraints limits the topic of a space wargame. The political constraints are reviewed followed by the technical constraints.

The USAF objectives in space are to "...preserve free access to, and transit through the aerospace ... {and} achieve freedom of action {in space} for friendly forces while denying or deterring enemy actions contrary to national interests" (55:iv; 54:2-2). Put another way, the Air Force must be prepared to wage war in space based on the US dependence on space, the USSR's assets there and the threat to the US in space (34:43; 8:45-46). The US has used space for military purposes since the inception of the space program (15:16-19; 35:157). Nevertheless, the military use of space has been constrained by a number of international and domestic political factors.

The US is a signatory to a number of international treaties which limit activities in space, e.g. the 1963 Nuclear Test Ban Treaty, the 1967 Outer Space Treaty, and the 1972 ABM Treaty, among others (35:160-161; 40:14-15; 8:79-82). However, a careful review of these treaties indicates that they do not constrain military activities in space very much (35:174; 8:76). In 1981, the USSR proposed a treaty to ban all weapons in space (8:83-85,115-117; 30:196; 35:169; 40:16). Domestically, some have argued that this proposal offers a unique opportunity to protect the sanctuary of space and keep the peace (18:61-62,70; 12:235; 29:168; 26:43). Others have argued that the proposed treaty would be disadvantageous to US national security interests (40:16; 8:85-90; 31:74-75,77,79-81). The debate on weapons in space has not only focused on the use of anti-satellite weapons in space but also on the Strategic Defense Initiative (SDI).

The SDI's need to employ weapons in space for ballistic missile defense (BMD) has engendered both proponents (40:14,21; 15:18; 37:28; 7:72; 47:3; 43:55) who feel that SDI is absolutely necessary for future deterrence, and opponents (22:27,31: 26:38; 18:67-70; 17:60) who argue that SDI is the greatest threat to peace and stability since the invention of the atomic bomb. At a minimum, the SDI would require changes to the 1972 ABM Treaty if weapons are to be deployed in space for BMD (8:90). Moreover, within the US government, these issues have been, and will continue to be, debated each year as both the Congress and the Air Force itself debate policy and budgetary issues (8:17-18; 72:17) on the appropriate military use of space. The debate will likely continue with various constraints applied and withdrawn in time. Future political constraints may include limitations arising from a space arms control treaty or from a more limited "rules of the road" treaty (40:17). The bulk of political constraints are likely to come either from Congress in the form of an ASAT ban, or from Congress and the Air Force hierarchy in terms of fiscal constraints. Political constraints on the military use of space are self-inflicted.

Technically, space operations are both complicated and expensive. Tremendous propulsive power is required to place each pound of mass into orbit. Thus spacecraft are confined in terms of their size (volume), weight, and electrical power available, necessitating complex spacecraft designs built to maximize the satellite's performance within the engineering confines. The complexity of the designs added to the cost of the booster or Space Shuttle ride makes for expensive aerospace vehicles, and hence a limited number of them. Propulsion is the most limiting technical factor in space operations, and it limits both the selection of orbits and the ability to change orbits. Achieving orbit and operating in the harsh environment of space is a technical challenge, and it will remain so for quite some time. Both politically and technically the Air Force is limited in what it can or cannot do in space. But these constraints are no different for the Soviet Union; and in fact, the Air Force has wide latitude with space forces even within existing political guidelines. Technology is more constraining than political factors are.

DOCTRINES AND STRATEGIES

Space doctrines, and strategies for using space systems, are relatively new. The U.S. Air Force's air doctrine had many years and the historical experience of two World Wars to develop before it was politically constrained in 1964. This was based on a fear of escalation of war to a nuclear war (25:16). Space doctrine is new by comparison and has no historical base for expression. Space was first considered as part of basic doctrine when General Thomas D. White invented the term "aerospace" in the late 1950's (25:17). Space was mentioned in the various changes to the Air Force's basic doctrine; but space warfare was first implied in the 1979 version of AFM 1-1 when space defense was described in terms of "hostile acts" (25:15). Air Force Manual 1-6, Air Force Space Doctrine, published in 1982, attempts to better define the subject (55:--). Lt Col David Lupton, USAF (Ret) (39:40-41), has noted that there exist four schools of space doctrine. The four schools are: the sanctuary school, the survivability school (there is no survivability in space), the control school (like air control), and the "high frontier" school which seeks to attain preeminence in space. Statements corresponding to each of the schools can be found in different sections of AFM 1-6 (55:--). The purpose here is not to analyze the different schools or their implications; but rather to point out the great diversity of thought on whether, and how, space wars will be fought. This has impeded the development of strategy because the strategy depends on the doctrine. The creation of US Space Command should help this situation, since there is now a focal point for thinking about these issues in the US military. The Soviets evidently have strategies for the use of space to deny the US superiority there, and maintain a peaceful sanctuary in space (11:458). The changing nature of space doctrine may be a necessary evil, for as Lt Col Lupton points out: "As technology matures, will the doctrine evolve through sanctuary to the high ground?" (39:45). He goes on to hope that we will work on the doctrine before the technology is developed and employed (39:45). The doctrine may need to be rethought without prior constraints and using an applicable subset of war fighting principles (39:16). Air University can take a leading role in the development of space doctrine if the students and researchers studying these issues have the right tools.

WARGAMING POSSIBILITIES

Space then offers some unique capabilities, along with attendant limitations, which one can explore in wargames. To demonstrate the characteristics of the space environment and the utility of the current space systems, one would want to demonstrate the motions of satellites around the earth. Different orbits ought to be illustrated to show the differences in satellite coverage of the earth in the force enhancement role. The capabilities of single satellites along with multiple satellite constellations should be illustrated. One might want to demonstrate the potential effectiveness of survivability measures for space systems (88:--; 33:96; 5:36-40). Future trends here may include efforts to service, and make more survivable, satellites in geosynchronous orbit (20:68-69). If aspects of space warfare are to be taught, some basic ideas ought to be presented. For example, most satellites are not continuously tracked by ground-based sensors. There are gaps in our ability to track satellites (both someone else's and our own) based on the satellite orbits and the location of the ground sites (91:--). If hostilities occur which involve space systems, "any battle in space will feature contestants wearing blindfolds that can only be removed for short (different) intervals" (25:21).

If weapons systems are to be studied by space strategists, then additional questions may arise. ASAT effectiveness or ineffectiveness should be demonstrated through information on the trajectories and timing of any potential attack (5:36,38) Timing is crucial for there are only certain times when a target satellite may be in view of an ASAT system, and the timing relationship among multiple attacks should be shown (88:--). Trade-offs between higher and lower altitude orbits for protection against ASAT attacks (39:38; 5:38) should be considered. To study certain SDI scenarios, it would be necessary to look at the various phases of ICBM flight, both separately and together. One would examine pointability and timing constraints for the boost, mid- and terminal phases of the flight to show the relationship between the weapons and the missiles in the space-to-space environment. For example, one could show the motion of the weapons satellite, and why one satellite cannot do it all. One might look at possible countermeasures of space-based BMD (26:34,37-38) and strategies to defeat them. Or one might look at the ability of a surveillance and command and control segment to contribute to space-based BMD (52:1,7). By looking into these subjects, the student achieves an awareness of the space environment, the missions and functions of space systems, existing and possible strategies and some important insights into possible engagements.

There are many possibilities for space modelling in wargames. The examples cited above are illustrative and may be thought of as candidate areas for inclusion in wargames. Before specific recommendations are proposed, the study turns next to a look at wargames.

Chapter Three

WARGAMES

Wargames have been used to develop military concepts since 1824 (73:1-25) with less formal versions used prior to that. This chapter will look at wargames: what they are, how they are used, the different types of games, and their benefits and limitations. A plan for the introduction of space assets into Air University wargames will be proposed. Three audiences have been identified, and the learning objectives and information needs of each audience will be presented. The chapter will conclude with an examination of the information needs of the audiences with an eye toward selection of a subset of these for di play use.

PURPOSE AND USAGE

A wargame is, in some sense, a simulation. What is a simulation? "A simulation is an operating representation of selected features of real-world or hypothetical events and processes" (73:1-1). From this definition we have (1:8) the definition of a wargame:

> A simulated military operation involving two or more opposing forces and using rules, data and procedures designed to depict an actual or hypothetical real-life situation. It is used primarily to study problems of military planning, organization, tactics or strategy.

Note the use of the terms "rules," "data" and "procedures" in the definition. These evidently are important parts of wargames (73:3-1 - 3-15). As the DOD definition states, wargames are used to study problems; that is, there is always an objective. This is followed by scenarios and models. Wargames require players and controllers; and a wargame is useless if the results are not analyzed (62:4; 66:4; 73:1-7; 96:--). Given this description of what a wargame is, let's look at why organizations go to all this trouble. We look next at the purposes and uses of wargames.

Wargames serve a variety of military purposes. The Joint Chiefs of Staff's Basic Policy Guidance on Wargames lists the following uses of wargames:

> The Joint Chiefs of Staff recognize the importance of using wargaming to aid in the analysis and evaluation of war plans and crisis situations; to the employment of major military forces; to test proposed strategies, tactics, concepts, organizations, and weapons systems; to educate key military and civilian personnel; and to reinforce interagency communications (60:1).

Wargames have both benefits and limitations. Wargames give the players the opportunities to learn from their mistakes at no cost (73:1-1, 38:22). Moreover, one uses actual or planned weapons systems under the pressure of time, with imperfect information to achieve a multitude of objectives (73:1-26; 38:23). "When, as in atomic warfare, there are no precedents, no historical examples to furnish guidelines, wargaming creates its own history of artificial wars" (73:1-25). One can practice wartime decisions (66:47,50) and model the escalation of warfare (65:x). Moreover, players probably "...learn more than they realize at the time" (73:1-26). The danger here is that they are learning the wrong lessons due to errors in doctrine or strategy (66:50), unrealistic models of forces and weapons, or erroneous decisions by umpires or controllers (73:1-29 - 1-30) among others. The key to avoiding these disadvantages is to analyze the wargame results and to evaluate them within the context of the game's assumptions (74:56-57; 62:12; 73:1-30). The greatest difficulty is due to "...unknowns {which} cause...deviations between predictions and reality" (66:38). These can occur when one models problems which do not lend themselves to precise definition. Lt Col Fox (66:29-31) calls these "squishy" problems and modelling them "...takes one from the realm of physical science to social science." "Squishy military problems are difficult to analyze using (models, simulations or games), but there are few alternatives" (66:43). Success in using wargames comes from the application of "sound military judgement" when interpreting the results (74:57). Some examples will help illustrate wargaming use.

Wargames are used in a variety of military and defense related organizations. Large wargames and models of war usually are built from a combination of smaller models along with the ways of combining them to fit the objectives of the games (73:1-6). The Office of the Joint Chiefs of Staff has a Joint Analytic Warfare System (JAWS) run by their JAD Division (now called J8) (66:25). The National Defense University uses wargames and simulations to acquaint the students with the various aspects of national power available within the international arena, among other uses. NDU's system is being modified for use by the JCS (38:22-29). The RAND Corporation has developed a RAND Strategic Assessment Center (RSAC) for use by the Air Staff, the Office of the Secretary of Defense and the Defense Nuclear Agency. RSAC is a large, multi-year effort "...to make wargaming more efficient, rigorous and analytical" (65:v). RSAC is intended for a variety of users, and models strategic alternatives and decision making. Future plans call for the incorporation of space capabilities (98:--). The Lawrence Livermore Laboratory has developed a strategic wargame called JANUS. It is noted for its user friendliness and color graphics displays; it motivates the war-gamer (66:27-28). United States Air Forces Europe has developed a Warrior Preparation Center to exercise senior level battle commanders in how to prosecute a theater-level war in Central Europe (90:--). Wargames have been played at the Naval War College since the late nineteenth century (1:118; 66:11). The Naval War College has used a variety of computer systems to assist them in the conduct of the games (1:118-121), and they conduct approximately 50 games each year (62:3). Air University has used wargames as part of its curriculum for a number of years, and plans to soon install a new capability called the Command Readiness Exercise System (CRES) (24:8-9). The Air Force Wargaming Center at Air University will operate CRES. Many organizations use wargames, and the wargames serve a variety of purposes. The many uses of wargames has resulted in classifications of wargames.

CATEGORIES OF WARGAMES

Classifications of wargames are arbitrary, and some are quite extensive (66:5-7; 73:1-14; 62:5). This study combines the referenced classifications into those depicted in Table 1. The classifications are important because in the course of the analysis the author will show that space systems ought to be modelled for both uses, at all scopes and using each technique listed. The use and level of modelling will differ depending upon the

USE	SCOPE	TECHNIQUE
Educational	Local/Tactical	Manual Games
Analytical	Theater/Operational	Computer Assisted
	Global/Strategic	Computerized Games

TABLE 1 - Categories of Wargames

proposed application. Before discussing the specific applications though, the different classifications, their advantages and disadvantages will be reviewed.

Many authors ascribe two broad purposes to wargames: educational and analytical (38:22; 73:1-10; 1:6-8). Educational wargames which include both "training and operational" games (1:8), "provide military commanders with decision making experience"; while the analytical use of wargames "provide(s) military commanders with decision making information" (73:110). These can, and do, overlap (73:1-10). Wargames expose command personnel to "the factors that influence the outcome in conflict situations" (71:3; 38:25). Wargames can be used to examine a problem or scenario many times, repeating the sequence with changes in data and/or decisions (62:8,15; 73:1-27). One can use wargames to look at both current and proposed weapons systems, doctrines, and strategies (1:6-8). The analytic use of wargames includes the use of simulations or wargames for research. "The research game, the most complex,...requires careful preparation to achieve maximum objectivity and is usually designed to study future technical and strategic problems" (1:8). This type of game requires a lot of work to test the validity of the game itself via sensitivity analyses (1:313) before the results can be used. Wargames can be used for training and operational education as well as the analysis of operational problems and research. Wargames also have different scope.

The scope of a wargame or simulation is defined as listed (62:5) in Table 1 in terms of the area of interest and the size of responsibility of the players (73:1-13 - 1-16). Players should experience the effect of being the Commander or a member of the staff of the units being simulated, and they should have the ability to make decisions on the movement and employment of the forces (10:38). It is important not to mix the scope in any given game. One should not be the "Commander-in-Chief and a Colonel" in the same game (10:42). Thus a game should concentrate on one of the three levels: local, theater, or global.

The technique used for a wargame or simulation, whether manual, computer-assisted, or computerized; depends on both the objective and the resources available. "Manual games can be played by organizations that cannot afford, or do not want computers or other simulation devices" (73:4-1). Manual games have the advantages of simplicity and flexibility (73:1-6,4-2; 96:--). They are particularly well suited for incompletely defined problems, to enhance "...the players' background for future study and analysis", and to test the game via player feedback before computers are utilized (64:3). Manual games have the disadvantages of usually being man-intensive (64:3), slow and cumbersome (73:4-3 - 4-4). Computer-assisted games provide computer models for portions of a game which are suited to computer modelling because they are well known. They can assist an analysis which uses manual methods. For example, this study will recommend a computer modelling of orbit prediction and trajectories because these are well known and can be run relatively quickly.

The use of mixed manual tools and computer models has a historical basis. Large computerized wargames which were built in the US and the UK in the late 1970's were found to be useful in the educational role, but they were useless in a research role because there were too many factors modelled in the game out of view of the researcher. Thus researchers have "...increasingly switched their attention to small-scale simulations in which the impact of each factor can be analyzed in some detail" (10:46-47). Computerized games enable the players to think more by freeing them from performing bookkeeping functions (66:12; 68:121). They also enable one to repeat scenarios many times rapidly (73:6-27), and then offer the opportunity to play the game in continuous time (as opposed to the discrete time steps usually found in manual games) (73:3-15). The disadvantages of computerized models include the aforementioned complexity for some research applications. Programming computer models is both difficult and time-consuming (73:6-28), and the complexity increases as the size of the game increases. Moreover, to leap into the development of a computerized game may "...lead to an over-reliance on the intellect, and a neglect of other, equally valid mechanisms such as intuition {and} gestalt understanding..." (75:33). The three techniques used to conduct wargames and simulations each possess advantages and disadvantages, and these must be considered when choosing a technique for a specific game.

The classification of wargames described above provides a framework for discussing the introduction of space into AU wargames. There are other important factors when classifying games to include the manner in which the game is handled (slow, real-time, or speed-up); the method of modelling systems and uncertainty; and how the game is conducted and evaluated (free, rigid or semi-rigid) (73:1-23). These will be used as necessary later. The study now turns to the question of how to incorporate space systems into the wargames and curricula at Air University.

A PROPOSAL FOR INCORPORATING SPACE

Chapter One provided a partial rationale for increasing space play in wargames. This section expands on that rationale identifying a specific approach which takes into account the different requirements of different audiences. Space wargames offer a unique opportunity to explore concepts and strategies, that otherwise would be unavailable. Warfighting is the complex interaction of man and machine (56:2-4), and space systems are some of the most complex machines used by the military. Thus space warfare and the preparation for it, promises to be one of the more complex educational challenges the Air Force faces. It is Air Force policy to: "...increase space involvement in Air Force Professional Military Education (PME) {and to} increase the general space awareness within the Air Force" (56:8-7). This need is recognized because the technical constraints on operating in space make space operations very different from air operations for the reasons given in the second Chapter. PME though must "...cater to a wide audience having diverse backgrounds, {so it} is restricted in what it can do" (66:49). PME includes not only the curriculum developed to directly teach principles to the students, but also the play of wargames by the students for the indirect teaching of concepts. Thus the audience in both cases is all the students at ACSC and AWC. A third audience would include those space-oriented students who want to investigate specialized subjects. The next few paragraphs will clarify the distinctions.

As part of the basic curriculum, the students should understand fundamental principles of space operations. Displays will be proposed which are designed to assist in this task. In addition to the basics of space operations, each student must be made aware of our growing dependence on space systems (71:47; 97:--).

One of the better ways to instill this in the students is through space integration into the planned wargames of CRES. "A major goal of wargames is to raise issues, including issues related to space and our dependence on it" (89:--). The force enhancement capabilities of surveillance, reconnaissance, weather monitoring, navigation and communications can be introduced into the wargames (71:47), in many instances via changes to only the scenario. Displays to bring home the dependence of our terrestrial forces on space systems will be proposed.

The relative immaturity of our historical experience, doctrine, and strategies in space, and the need to test new space doctrines and strategies calls for a different wargaming capability than any planned to date (see later paragraph on CRES). The capability to depict current and projected space capabilities requires a more diverse and flexible tool than those needed for the audiences cited above. Moreover, the audiences are different. Not every student will be interested in trying out new space concepts or testing new space strategies; but to do so will take some familiarity with space capabilities as a prerequisite (38:23). If wargaming is useful for learning about war here on earth, would not a space wargame teach us some important lessons about any future conflict in space?

A space wargame involves a number of unknowns; and because of the "squishy" nature of the problem (66:29-31) the students of a joint (AWC/ACSC) space wargaming elective course held in the Fall of 1986 agreed that a step-by-step approach was needed to introduce a space wargame (94:--). The approach calls for the creation of one or more board games in conjunction with space displays to test out ideas and concepts for a space wargame. The initial audience for this capability would be AWC and ACSC students knowledgeable and interested in space activities, as well as any researchers from the Center for Aerospace Doctrine, Research and Education (CADRE) (24:9) who are working on space-related projects. Figure 3 summarizes the overall approach to meet the needs of all students and researchers. The research audience may grow when Air Force doctrine development is transferred to Air University from the Air Staff. Board game development is crucial because there are no commercial board wargames that model our space capabilities (4:193-228; 10:--). The imprecise nature of what to game calls for experimentation with board games and display oriented simulations before the precise, step-by-step requirements of a computerized space wargame can be defined (73:1-5,4-3; 68:117,121; 10:42; 64:3; 1:26-27). Displays are important in this application because the operations are not intuitive. Flexibility in display capability is required so that many alternatives can be viewed. Display oriented simulations used in conjunction with a manual game will lead to the development of a true space wargame. Once such a game is developed, possibly as part of a future AWC or ACSC elective (71:46), CRES can then be used to create a tailored exercise and game (24:8-4; 66:59). Such a game might then be useful to try out contingency plans for US SPACECOM, although this may not be possible for quite some time. Moreover, with further testing by the elective

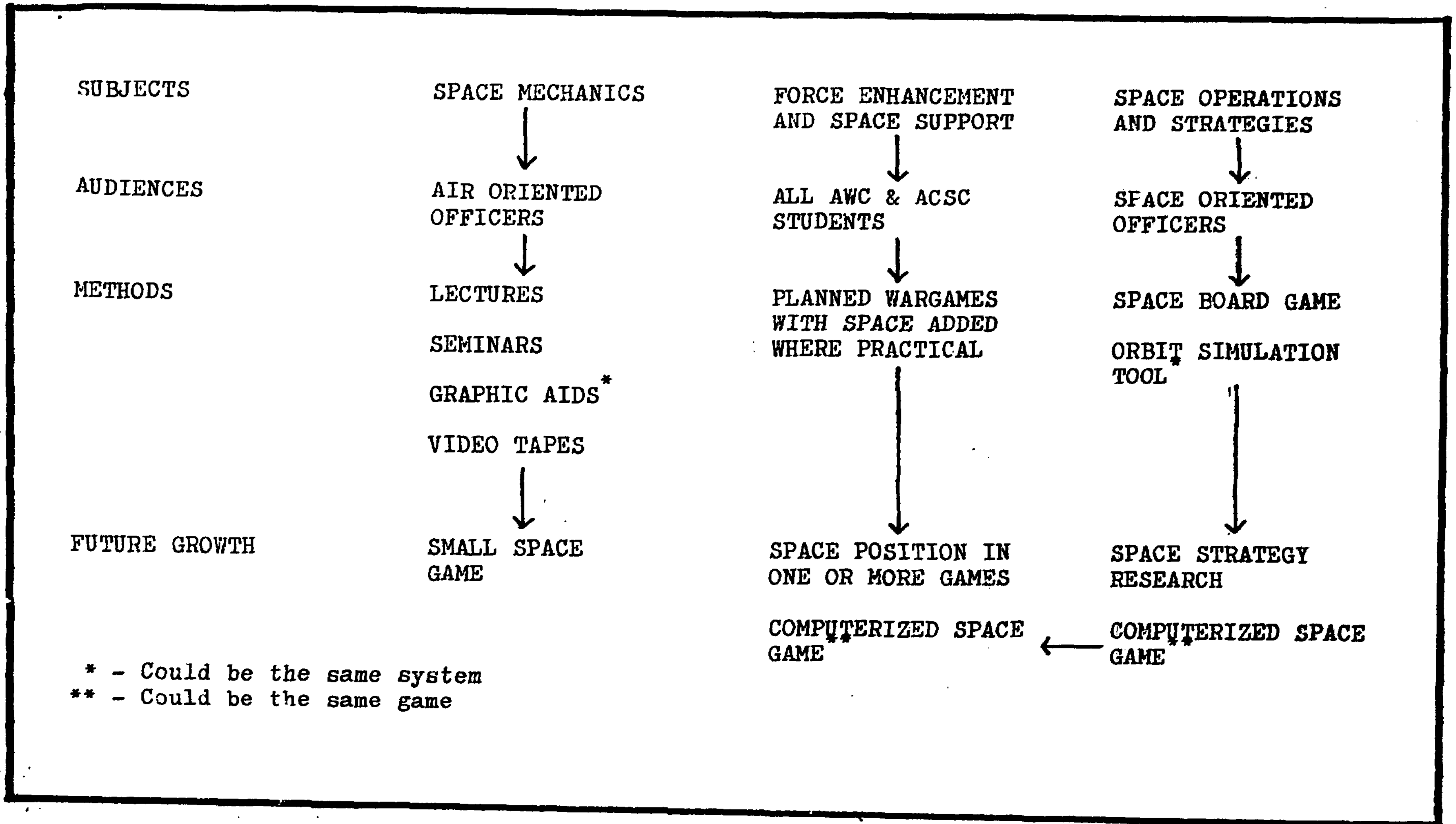

Figure 3 –– PROPOSED STRATEGY FOR THE INTRODUCTION OF SPACE WARGAMES AND DISPLAYS

students, the game could be used by all students as part of the curriculum. The development of space displays and a space wargame will require the use of displays by different audiences; and the task of creating a space wargame will require the achievement of some interim milestones. The first audience considered will be the students experiencing their intial introduction to space systems.

THE INTRODUCTORY AUDIENCE

Students being introduced to space operations should be clearly and concisely exposed to the basic principles of space operations. The framework for space education must derive from the learning objectives for the space portion of the curriculum at each school. The objectives of the introduction to space at ACSC are listed in Table 2 (57:257). It is assumed that AWC requirements are a subset of these.

Comprehend how characteristics of the space medium influence the characteristics of space forces.
Explain how the characteristics of operations in the space medium influence military strategy for the application of space forces.
Explain the advantages of various satellite orbits for conducting military support missions.
Explain why space is well-suited for the military support mission of communications, navigation, and surveillance.

TABLE 2 - Introductory Space Learning Objectives

To accomplish these objectives students must be exposed to fundamental principles of spaceflight, dispelling misconceptions of space activities, while reinforcing a non-mathematical concept of orbits (83:17-3,17-5,17-9). Appendix A describes the fundamental principles of orbits and summarizes the common myths encountered at ACSC (83:17-11 - 17-35), they are copies of handouts provided by the faculty to the students. These principles are not intuitively obvious. Based on the author's experience in conducting the seminar, and in order to get the "first principles" across to the students and dispel the myths; it was necessary to find the answers to a sequence of questions. The questions were: how does a satellite achieve orbit? How does a satellite stay in orbit? How fast does the satellite travel? What does the flight path of a satellite look like as viewed from space and as viewed from the earth? What are the main orbits used? Why are the different orbits used? The answers to these questions were the information needs of the students to meet the objectives of the lesson.

To answer the different questions and meet the information needs of the students, the author used various analogies to bring home the points. The approach will be described, and recommendations made. To answer the first two questions, the analogy was made between spaceflight and the flight for a bullet. If one shoots a handgun at a 45 degree angle, the bullet travels both up and out. If a rifle is fired in the same direction, the rifle round goes higher and farther. If an artillery shell is sent in the same direction, it will go higher and farther than both the bullet and the rifle round. The point was then made that an intercontinental ballistic missile (ICBM) sent in the same direction will go higher and farther still. The difference in each case is the amount of "oomph" (thrust) applied. Variations in directions were noted, with the point being made that if one shoots any of these weapons straight up, each would come straight down. It was noted that the faster the projectiles' speed, the further they went. See Figure 4. Finally it was noted that in excess of a certain thrust and hence speed (an orbital injection velocity), the satellite will fall towards earth but have sufficient velocity (energy) to continuously miss hitting the earth. It was pointed out that sufficient thrust could be given to escape the attraction of the earth altogether (59:2-20). The satellite stays in orbit due to the attraction of gravity with its orbit completely determined by the velocity (speed and direction) at the end of the launch phase. The satellite travels around the center of the earth returning to the point of orbit injection (rocket cutoff), repeating its path over and over. After launch the satellite is very much like a drone in a racetrack flight path. It was noted that for an eccentric orbit such as the one of Figure 5, the satellite goes very fast near the earth and slows down as it gets further away. The velocities for a typical LEO and HEO were given and the differences noted. The author believes that the only way to adequately depict the flight path of the orbit of Figure 5 was through the use of a globe with the tip of a pencil tracing out the path of the satellite around the globe. The amount of time it took to complete an orbit was compared to the time of one earth rotation, i.e. a day. It was noted that what the satellite can "see," or who can "see" the satellite is a matter of two simple motions: the orbit of the satellite and the rotation of the earth on its axis through the poles. The effect of these two motions occurring simultaneously was examined. An earth-to-space view of the orbit was discussed (no illustrations). The Molniya orbits, and then the geosynchronous orbits were described to show the advantages for communications. Medium altitude orbits for navigation applications and low earth orbits for meteorological observation were subsequently illustrated. Table 3 summarizes the information needs which were met.

This pedantic review of one seminar's activity is meant to illustrate the fact that better displays would have enabled one to present the materials more concisely and consistently. Someone once said: "a picture is worth a thousand words"; and in the author's opinion, displays of the different ideas would have saved considerable time. Moreover, although the faculty provided

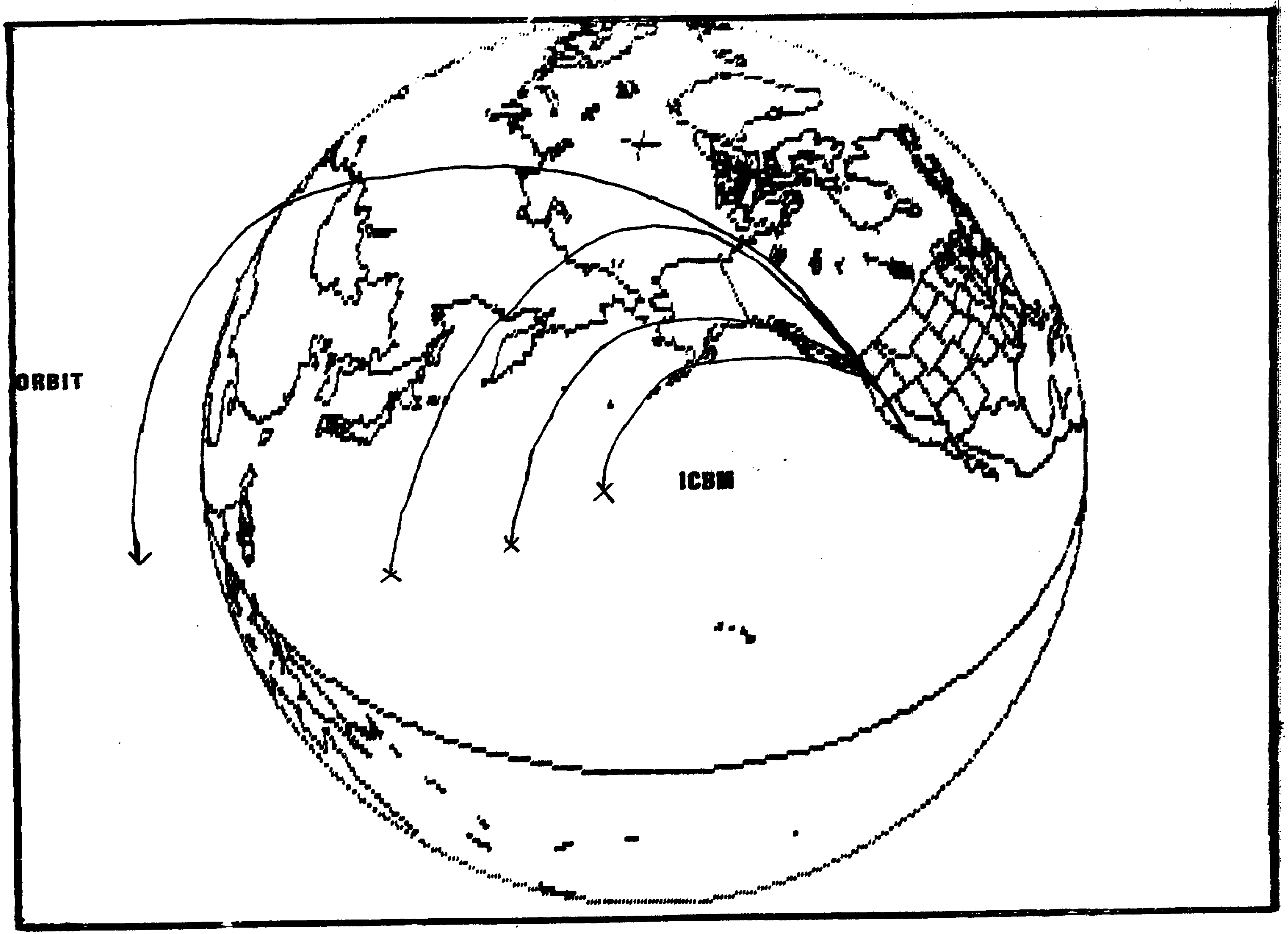

Figure 4 -- BALLISTIC ANALOGIES

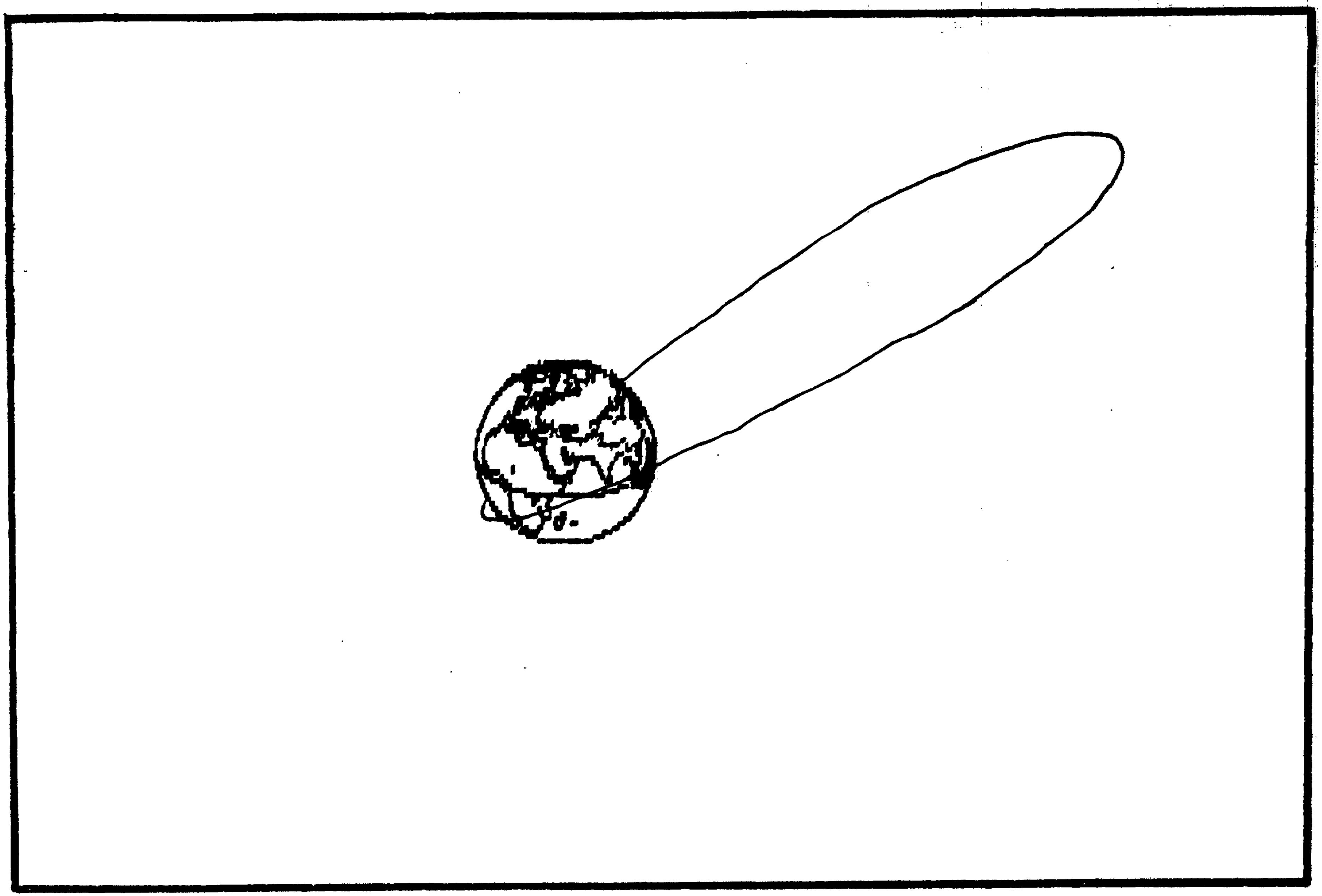

Figure 5 — MOLNIYA ORBIT

Ballistic Analogy - Very Fast Bullets

End of Launch Determines Subsequent Motion

Satellites Travel Around the Center of the Earth and Repeat

Speed Depends on Altitude

Two Simple Motions Involved: Orbit of Satellite
Earth Rotation

Four Main Orbits:

TYPE	EXAMPLE	ADVANTAGES
Polar LEO's	Weather	Worldwide Coverage Close to the Earth
Circular MEO's	Navigation	Simultaneous World-wide Coverage
Elliptical MEO's (Molniya)	Communications	Good Coverage of Northern Hemisphere
Geosynchronous HEO's	Communications Surveillance	Stationary as Viewed from Earth

TABLE 3 - Introduction to Space: Information Needs

vugraphs depicting many of the first principles, a globe was needed to properly illustrate some of the latter concepts. Different seminars were left to different devices. A good capability to display the information preferably in conjunction with a videotape, would enhance the consistency among the seminars. Although the information needs were discussed for the introduction of space systems in the curriculum, these same information needs should be reinforced later in the curriculum. For example, when one describes how navigation satellites enhance navigation, the faculty could introduce the subject using displays of just the orbits used by navigation satellites (80:--). Note that Figure 4 which was used in the ballistic analogy can be used to describe launch trajectories when space support is discussed. The information needs of students being introduced to space activities include certain fundamentals of space flight; and the pictoral representation of those principles should enhance the conciseness and consistency of the space curriculum at both the ACSC and the AWC.

THE CRES WARGAMING AUDIENCE

The next audience to consider is the students participating in wargames at Air University. What are their information needs with respect to space when playing the different wargames? To answer this question, one must first understand the different wargames. The CRES wargames will be reviewed. Then the over l goal of including space in the games will be explored, and the specific learning objectives will be determined. After determining the learning objectives, the analysis will proceed with candidate methods of achieving the objectives; and from there, the information needs of the players will be proposed. The analysis begins then with a summary of the different CRES wargames.

CRES will include capabilities to execute wargames for the different Air University schools (AWC, ACSC and Squadron Officers' School), to conduct joint wargames with other service schools, and to test operational plans through wargames conducted by the Air Force major commands themselves (24:8-9; 66:xi,1). This study will examine only the first case, and only those wargames planned for use by the AWC and ACSC.

The first exercise considered is the theater-level wargame. This game will be a fairly comprehensive two-sided game designed to familiarize the students with a NATO-like air theater, the decisions required, and the constraints involved (85:3-5 - 3-7). The students will be required to plan and build Air Directives, Daily Ops Orders and Air Tasking Orders (85:3-1,3-5). Appendix B summarizes the educational objectives as they appeared in the CRES Functional Specifications (85:--). The theater-level game is one of the most important in the AWC curriculum (71:25, 96:--). Many aspects of theater air warfare will be modelled; and among these are some which may lend themselves to space inputs based on the force enhancement capabilities of satellites. For example, there is a pre-hostilities phase to the game (85:3-9); and some satellites might be available only in this phase if Soviet ASAT use is assumed in the scenario. Weather forecasts and communications requirements are part of the exercise. Reconnaissance is played, but the intelligence is altered only through the use of tactical reconnaissance (85:3-20). This exercise is meant to replace the "TWX" exercise currently in use at AWC (61:53).

The next CRES exercise is the Sub-Theater Exercise for use by ACSC to simulate a "joint command or component command at the Tactical Air Force (TAF)" level (85:3-28). The objective is listed in Appendix B (85:3-32). Weather effects are modelled, so there is some limited possibility of space asset involvement. This game will replace the FAST STICK exercise at ACSC (61:18).

CRES will include a Tactical Employment Exercise for use by SOS. This study considers ACSC and AWC wargames only.

CRES will also include a Strategic Nuclear Exchange (SNE) exercise for use by both AWC for "force planning and structuring" (85:3-99), and ACSC for "force structuring and employment application" (85:3-106). Since this game is to be used by both schools, not every objective is meant to be played at once. The combined list of objectives is provided in

Appendix B (85:3-94). Since the SNE includes a force buildup phase, satellites could be made part of the forces. Reconnaissance (85:3-98), surveillance (85:3-103) and strategic defense (85:3-91) are played. Employment of ASAT's or the degradation of space assets can be played as part of the scenario; that is, space has already been considered in the development of the game. The SNE provides a nuclear exercise capability for AWC and replaces "BIG STICK" at ACSC (85:8-9).

The final CRES exercise under development is one called HANNIBAL. HANNIBAL is meant to support both schools. It will be used for AWC's Rapid Deployment Exercise (RADEX) which is designed to exercise planning and use of the Crisis Action System. HANNIBAL is also meant for use in conjunction with ACSC's Joint Operation Planning System Exercise (JPLAN). HANNIBAL introduces students to the Joint Operations Planning System (JOPS) and the Joint Deployment System (JDS). The objective at both schools is to exercise the deployment of forces. Logically, one could follow this exercise with the Theater or sub-Theater exercise (85:3-127 - 3-128). Many factors including weather and communications are considered in HANNIBAL so there are opportunities for space play in HANNIBAL.

Although not described in the CRES documentation, AWC conducts an exercise on National Security Studies which includes decisions on the country's major weapons systems composition (71:10). "Space systems as an element of our force structure need emphasis" (71:29). However, the author can think of no peculiar displays that would enhance the play of the National Security Studies exercise.

Having reviewed the various exercises that CRES will support at AWC and ACSC, the question arises: how should space be played in the exercises, and to what extent? Some might argue that space systems ought to be an essential element of each game (71:46). Others argue that "...we must restrict the use of space systems in all exercises and war games to only those assets which will survive. We defeat the fundamental purposes of wargaming if we 'play' with assets we won't have in actual conflict" (5:49). The latter point is well taken, but it can also be used as an excuse for not including space systems in wargames at all. This is truly unfortunate because it is precisely for the reason that satellites are vulnerable that they must be portrayed in wargames. The objective of including space systems should be to show the students the capabilities and limitations of these systems (97:--; 96:--); and if the scenario includes a prehostilities phase, or if the level of conflict is such that satellite attacks are not likely, then satellite support should be modelled in its force enhancement role. Table 4 summarizes the objectives. BLUE and RED satellites should be degraded if the scenario calls for a level of conflict commensurate with ASAT activity. In other words realism, not overzealous emphasis nor unrealistic avoidance, is needed when modelling space systems in AU wargames.

Comprehend the importance of selected satellite systems in the force enhancement role in support of air forces.

Understand the effect of degraded space systems on our ability to conduct warfare.

TABLE 4 - Educational Objective of Including Space in Wargames

This realism can best be achieved by incorporating the effect of space system play early in the crisis scenario, and then doing one of two things in the rest of the wargame. If the scenario would not normally involve space threat activity by the RED team, then one should incorporate simple mechanisms to show the players that they depend on space systems for the support functions. If the scenario would involve RED space threat activity, then the support function should be degraded in some way to show the result of the loss of satellite support. The goal here is to create issues of our dependence on space assets (89:--). Moreover, the space aspects of the game should be very simple requiring no prior knowledge of intricate space systems. Otherwise, introduction of the space models may obscure the other more important objectives of the wargame (96:--). There may also be some advantages to incorporating RED space activity if it would be consistent with the scenario. Space assets should be played in the wargames in such a way that the modelling is as realistic as feasible, showing the players how much certain support functions depend on space systems, and indicating the degradation of support when, and if, the satellite systems are degraded.

Given the overall educational objectives as listed in Table 4, we turn next to specific suggestions on how to accomplish the objectives. These suggestions on ways to incorporate specific systems in the planned wargames are just that - suggestions. Another ACSC student (Major L. D'Gornaz) is conducting a detailed look at the space-related learning objectives for the wargames as his research project this year. His expanded set of educational objectives could lead to an expanded set of information needs. These suggestions are the author's means of illustrating the possibilities with an emphasis on the displays needed. If the suggestions are representative, the displays will suffice for the variety of ways one could model space in the wargame. Table 5 illustrates those areas where space could be modelled. Under space support, activities are listed which would enhance the game, but deal with space systems rather than a particular force enhancement capability. These include such things as ASAT use by the RED force, or BLUE force satellite status (91:--). A capability under development by the wargaming center, called INR, will handle intelligence modelling separately (91:--). From Table 5 it appears that satellite modelling is most applicable to the SNE exercise. This reflects the different usage of space systems in the different levels of conflict. As the chart indicates, planning should begin for the introduction of navigation modelling when the Global Positioning System (GPS) becomes opera-

Space Missions:	The Game: Theater-Level Wargame	Sub-Theater Exercise	Strategic Nuclear Exchange	Deployment Exercise Hannibal[1]
Surveillance	Not applicable	Not applicable	Play assets for ICBM or SLBM attack warning. Degrade or eliminate if RED threat used.[3,4]	Not applicable
Reconnaissance	Not applicable	Not applicable	Play assets in pre-hostilities phase for treaty verification. Degrade or eliminate if RED threat used.[4]	Not applicable
Navigation	Not applicable[2]	Not applicable[2]	Not applicable[2]	Not applicable
Communications	Play assets for comms connectivity. Degrade or eliminate inter-or intra-theater comms if RED threat used.[4]	Not applicable	Play as part of strategic comms connectivity. Degrade or eliminate if RED threat used.[3,4]	Play assets for comms connectivity. Degrade inter-theater comms if RED threat used.[1,4]
Meteorological	Play assets as part of weather model. Degrade quantity, quality or timeliness if RED threat used.[3,4]	Play assets as part of weather model. Degrade quantity, quality or timeliness if RED threat.[4]	Play assets primarily in pre-hostilities phase. Degrade or eliminate if RED threat used.[4]	Play assets as part of weather model. Degrade quantity, quality or timeliness if RED threat used.[1,4]
	Status of BLUE and/or RED space assets. Possible use of RED ASAT.	Not applicable	Order of battle of RED and BLUE Satellites. Status of ground sensor sites. ASAT use.	Not applicable

Notes: 1. Either one or the other mission should be played in any given exercise, but probably not both.
2. Weapons' accuracy should be modelled here when GPS becomes operational in the early 1990's.
3. In the author's opinion these are the minimum missions and games needed for space play.
4. Per Chapter Two, RED threat equals ASATs, lasers, attacks on ground facilities or electronic interference

TABLE 5 – Proposed Use of Space in CRES Wargames

tional in the early 1990's. Navigation modelling would involve improved weapons accuracies when GPS is operational, and degraded accuracies if GPS is degraded. Also if SDI is deployed, one would want to model the space-based segments of SDI in the SNE exercise, in a separate space wargame, or both. Additional environmental monitoring systems may be included as appropriate. There are many possibilities for modellig space systems in the CRES wargames, the author proposes eleven different areas for modelling with four areas deemed essential. The analysis continues with an examination of the information that the players would need to use the proposed models.

Players of the different wargames would receive information in a variety of forms. This study will consider two examples: using weather satellites in the Theater-Level Wargame; and the use of surveillance satellites in the Strategic Nuclear Exchange exercise. These cases have been selected to illustrate the different categories of information, and to identify that information which should be displayed. If weather satellites were modelled as part of the weather model, then the weather data would be available to the players based on the passes of the satellite over the theater's area of interest. But weather satellites are one of several factors used to predict weather. Thus if the satellites were degraded as part of the scenario (91:--), the data might be delayed to the players; its quality might be reduced, i.e. the predictions would cover wider resolution grids; or certain weather reports might be deleted. In this case, the players might receive a message report that the data is adversely affected and why. Some users in theater might have available the status and the coverage capabilities of the satellite. Status would typically include simply whether or not individual satellites of the constellation are operational, and the time of the next pass over the theater. The status might be updated via messages. This status and coverage data should only be available if real-world counterparts to the units in the game receive the data (90:--). For surveillance satellites in the SNE exercise, players would receive status messages and coverage data as depicted in Figure 6 for example. In addition, the players would receive message reports from the systems. For example, the surveillance system could report the occurrence of four RED force launches, delaying a subsequent report as to whether the launches are for satellites or ICBM's (91:--). One could degrade the coverage or timeliness of the report if the RED space threat is part of the scenario. Moreover, status information in the BLUE and RED space order of battle would likely be needed in the SNE exercise. In summary, four types of information are possibly available to the wargame players. The four types are: scenario inputs and events; status information provided via message and possibly displayed; satellite products which are either message inputs or transparent to the player until something fails; and finally, coverage plots for some constellations of satellites. This information provides the wargaming players the information needed to play space systems in the CRES wargames.

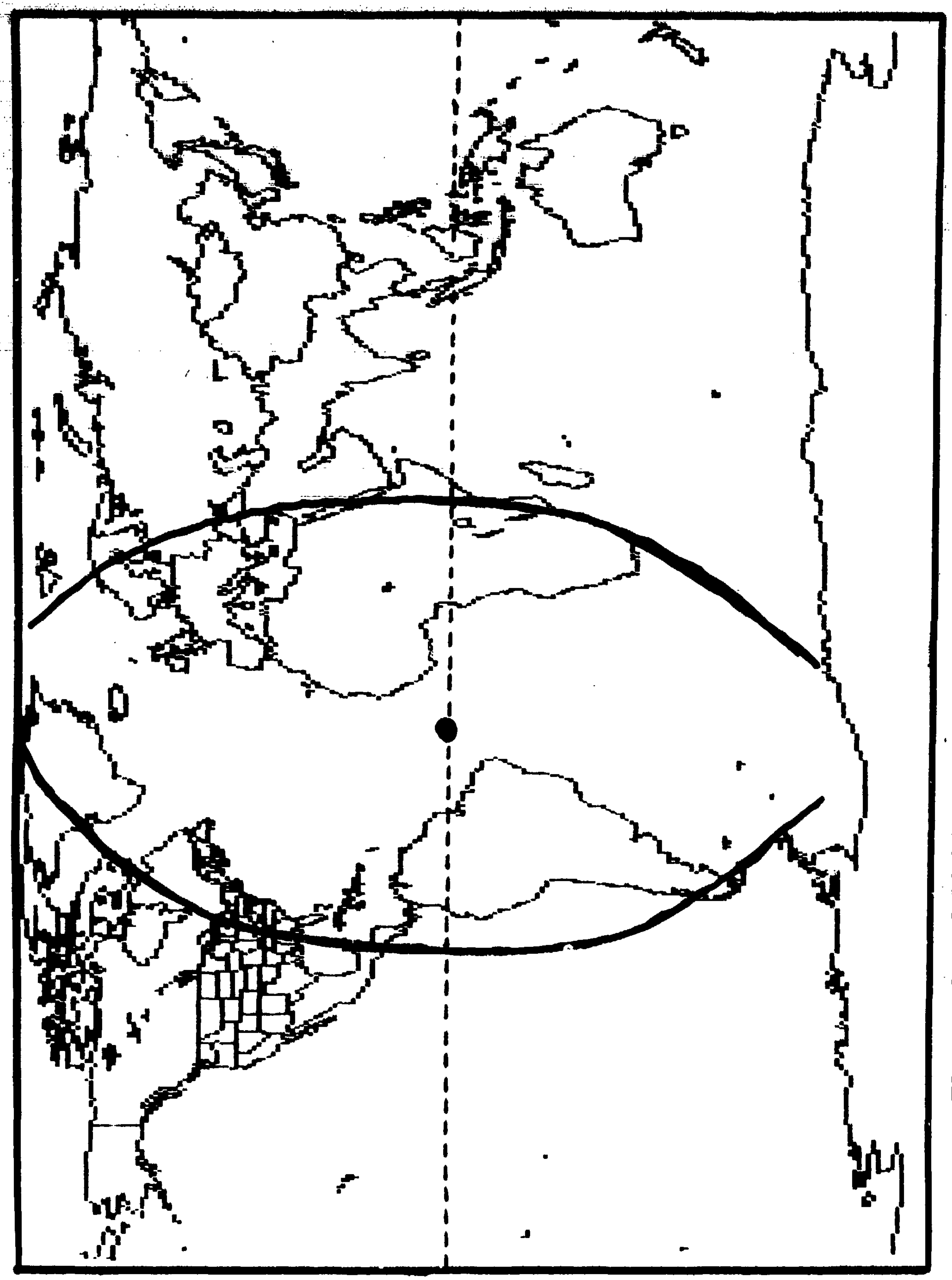

Figure 6 – GEOSTATIONARY SATELLITE COVERAGE

THE RESEARCH AUDIENCE

The research audience: who is it? What do they do? How do they do it? What are their information needs? This section will explore the answers to these questions in order to determine the display requirements for this last audience. The analyses will define who conducts space-related research at Air University, pose two major tasks for them, and propose a variety of ways for them to accomplish the proposed tasks. The author's main interest here is in satellite displays, or more precisely, orbit displays; so these will be the main focus of the discussion. As the analysis progresses, the reader will notice the subjective nature of the material; that is, the proposed method of supporting the research audience is very arbitrary. This should be kept in mind when reviewing the conclusions and recommendations.

The research audience includes those students, faculty members or staff researchers (from, for example, the Aerospace Research Institute) studying a question related to space. Based on the discussions within a Space Wargame Elective (see Figure 3) we can differentiate two different methods of research (94:--). These correspond to two major near-term tasks: development of a space-related wargame, and game-independent space-related research. As described earlier, wargames can be used as analytic tools to investigate concepts and strategies. The next few paragraphs will explore this subject in more depth. Then the analysis will focus on the needs of a space researcher over and above those for a wargame. First, we discuss the proposed approach to the development of a space wargame.

The section on categories of wargames described the rationale for a space wargame. Given the goal of creating a space-related wargame, what approach should be used? Immediate development of a computerized wargame is inappropriate when either there is insufficient data or the objectives are not clear (1:10). The latter is especially the case here; for the questions arise: what kind of space wargame? What should be the learning objectives? The Space Wargame elective, held late last year, did not definitively answer these two questions; but an approach was broached. That approach calls for the creation of one or more manual games related to space; examination and testing of those games next year by interested students (87:--); and then the development of a broader, computer-based game if needed. The computer-based game would be used by either space researchers or the general student audience, and it would be developed during or after the third phase of CRES. Any manual games which are developed will need thorough testing (87:--) both for their own effectiveness, and to work out problems before resources are committed to the computer programming. The approach chosen is to create one or more manual games for near-term use by interested students or researchers. The next question to address is: what kind of manual space wargame?

Many possibilities for manual space wargames come to mind, but the author will describe three ideas for further consideration next year by interested students. During the Space Wargame elective, Major Erik Anderson developed a communications satellite game (78:--). The object of the game is to maximize the support to the ground terminal customers through the positioning of geostationary satellites. Players learn some fundamentals of satellite operations, and they are exposed to operational constraints. The constraints include: the need to always be in view of a mission ground station; limitations on the amount of propellent available; the policy problems with launching quickly; and the time required to replace a broken satellite, among others. The rules and procedures call for events to occur every month, and players must provide coverage between both inter-theater and intra-theater nodes. The points awarded are weighted according to the importance of the nodes. Tallys are kept of the cumulative scores on paper; and to "see" the coverages, Major Anderson created a very simple display. It consists of a world map with acetate overlays indicating the possible coverage. By positioning the overlay with the satellite subpoint at the desired longitude on the equator, called a node, one can see the effect of using the satellite at the node. Figure 6 depicts a static representation of the display, assuming a minimum elevation constraint on the coverage. Imagine the satellite coverage lines sliding along the equator, and you will understand how his display works. Multiple overlays showed the overlapping effects of using multiple satellites. This game is very ingenious and would be very beneficial for students with little or no background in space systems.

Another ACSC student, Major Bruce Thieman, is creating a different manual space game as his research project this year (98:--). Major Thieman's game is a resource allocation game considering both the offense and the defense. The goals of this game are to expose the players to different satellite systems; create issues concerning treaty legalities; and to present the threats to space systems. The game is meant to be played by AU seminars with each seminar split into a RED team and a BLUE team. There are six players on each team representing a variety of senior military and civilian leaders. Each turn is two years; and the game consists of a board, requirements' lists for each player, a resources catalog, and a budget. During each turn, the teams develop and then maintain, a plan for the use and development of satellite systems--an architecture. Points are awarded for the number of working satellites available; and the points are weighted based on both the mission area and the level of conflict. Thus survivability measures are part of the game. This game is still under development, but it promises to be a comprehensive game dealing with space planning issues.

A third and final manual game could be developed based on the work of two other ACSC students this year. Major Michael Mantz (92:--) is researching the rules of engagement for any potential space conflict while Major Hal Hagemeier (87:--) is working on a project to describe the information needs of

CINCSPACE based on the threat. In the author's view, the results of these two papers could be used with hypothetical space threat scenarios to create a different manual space game. This game would be more constricted in time to a few days. The players would represent BLUE CINCSPACE and members of his staff. As the scenario develops, different threats to BLUE space assets would arise. The alternative courses of action would be developed by the players, and decisions made by the lead BLUE player. Points could be awarded by how well the players countered the threats, and by how many assets remained after the threat passed. Assets would include: a variety of force enhancement systems over which CINCSPACE has either direct or indirect control (87:--); the space support ground stations to operate the systems; the space tracking network to see into space; and the space control ASAT system. As much as practical, realistic timelines would be played against the various threats (ground, electronic, DEW or ASAT) to highlight the dilemmas involved (87:--; 62:11). The game might be expanded to include the different basing schemes under consideration by the SDI program. The players could learn the advantages and the disadvantages of the different force application alternatives. Development of this game will require more work. The referenced research reports must be analyzed, and the specific rules and procedures developed.

Based on the description given above of the three potential manual games, we seek the players' information needs with respect to displays. Every game needs a display even if it is only a blackboard. For Major Anderson's game, the players' information needs are met by the map and overlays as partially depicted in Figure 6. The players will use cards on each turn to learn the events, and scratch pads to keep track of the score. For Major Thieman's game, the players will be interested in a status board of some kind which shows the current status of the different satellite types. It may be useful to use coverage charts to help determine the performance capabilities for the different resource options available. For the hypothetical third game, the options and status displays described in Major Hagemeir's report would be of use in the game. These reports show the status of the various assets: whether or not they are operational; and if not, estimated time to return. Another status display would mirror the displays at SPACECOM. For the status of satellites in geostationary orbit, one could portray the information as indicated in Figure 7 (99:--). One might call up another standard plot: the status of a particular satellite would be depicted by where its ground sub-point currently is and what the post and future orbit motion will be. See Figure 8. Note that ground sensor locations and coverages are often overlayed onto these displays. One could also illustrate the options available as the different threats occur. Status displays could list the options as indicated by the headings illustrated in Table 6 (UU:--). Note that timing relationships are very important. Backup displays may be needed to show the rationale behind the entries in the last column of Table 6. The three manual space games provide many possibilities for displays.

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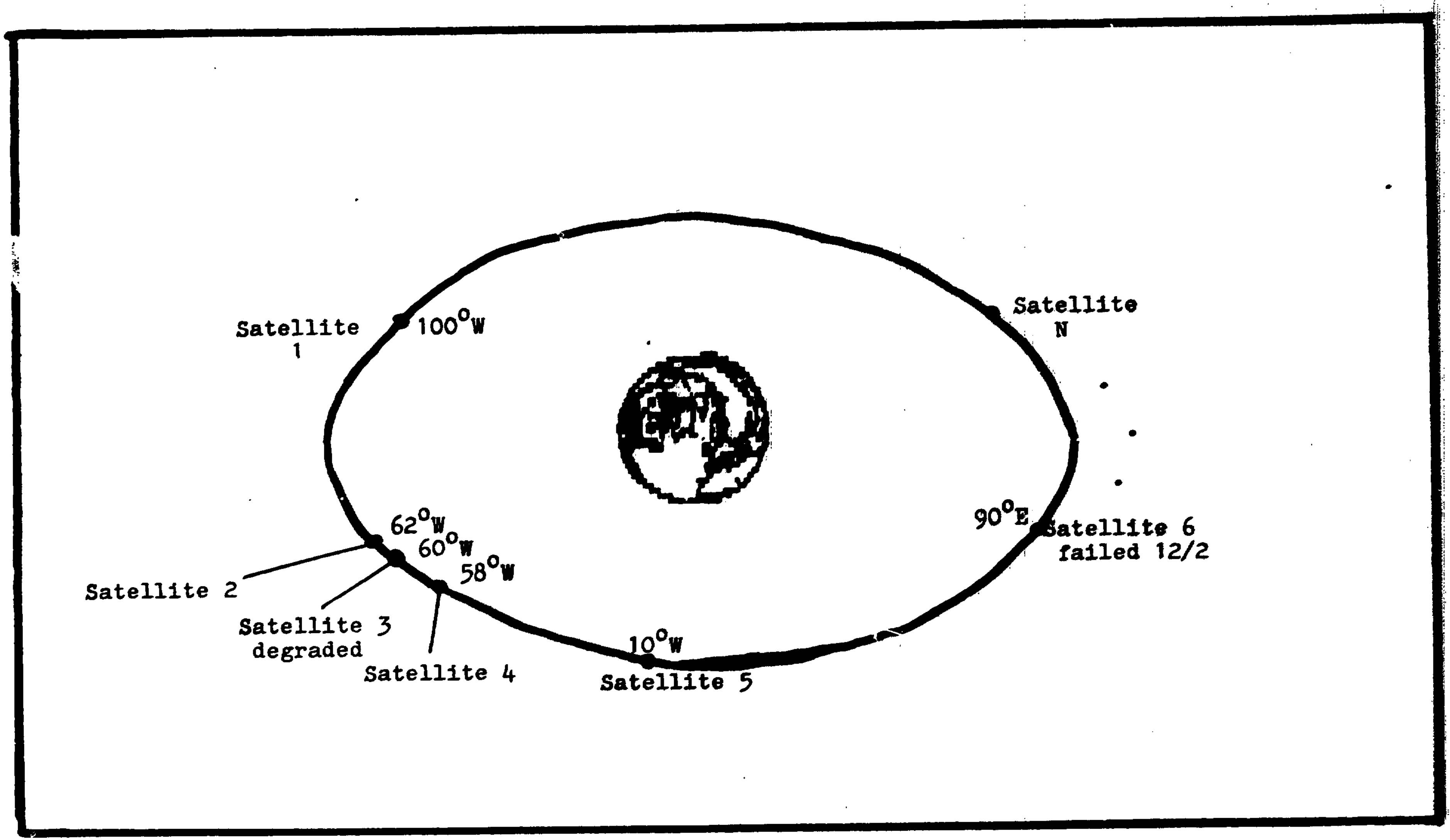

Figure 7 – GEOSTATIONARY SATELLITE STATUS

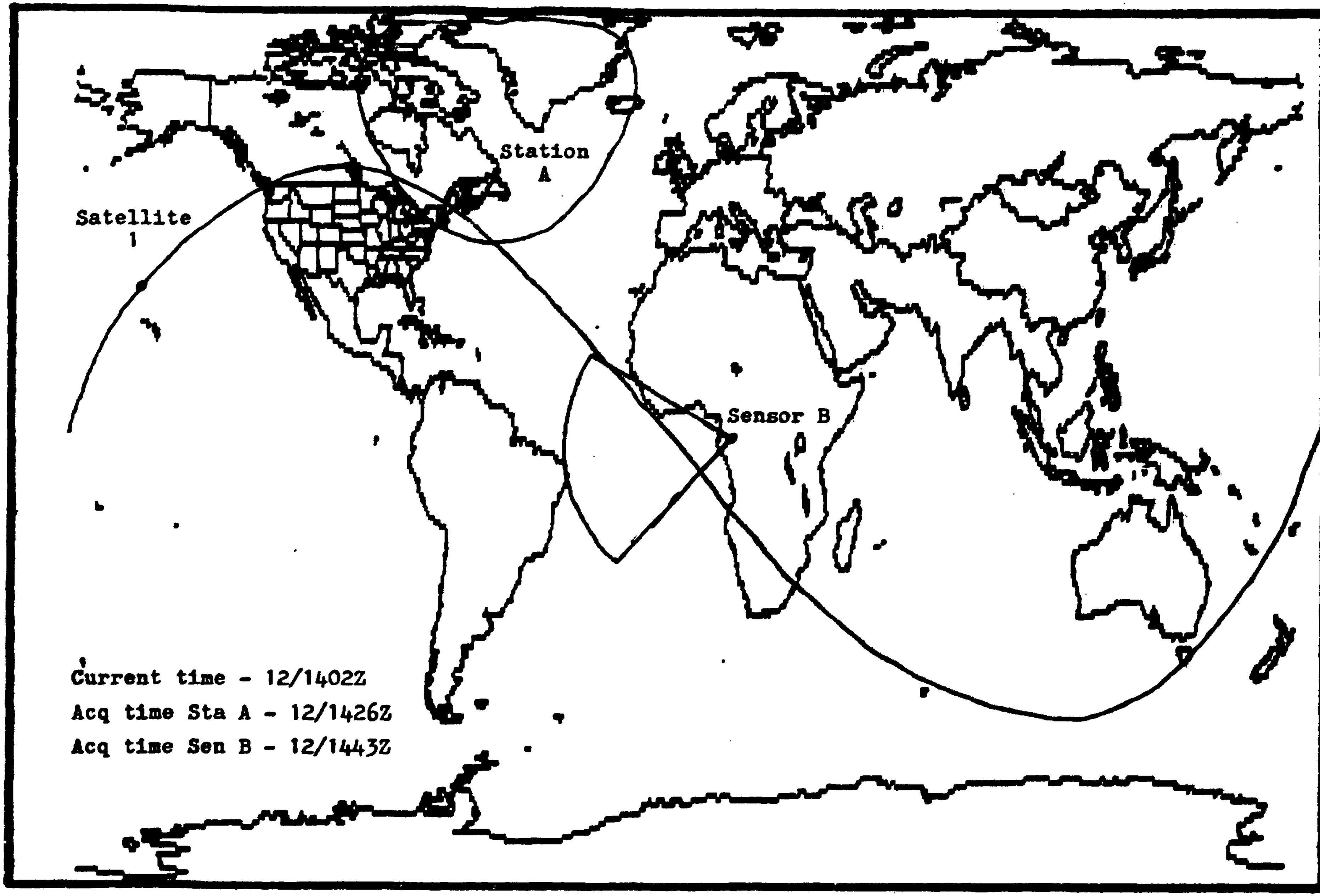

Figure 8 – ORBIT GROUND TRACE PLOT

TIME	EVENT	SYS	POSSIBLE CAUSES	ALTER-NATIVES	TIME TO REACT
12/2210	Failure	6921	Natural	Replace w/6201	7 Days
.	.	.	.		.
.	.	.	.	Launch 6819	6 Months
.	.	.	.		.

TABLE 6 - Typical Status Display

For the three games, the information needs can be summarized into categories. First, the players would need some type of status display to keep track of the ongoing status of their assets as the game progresses. Second, for some of the games an indication of potential coverages could be helpful. Since all force enhancement systems gather information (40:7), they look towards the earth, and coverage information is of interest. Finally, if important for the game, a description of timing relationships between planned or potential events could be used. This would be important when BLUE vs. RED threat scenarios are played. It is possible to differentiate the display related information needs into the categories of status information, coverage information, and timing data.

Despite the distinction made above, it is important to remember that these information needs are hypothetical because the games are hypothetical. Since a manual game will not be available and tested this year, one faces a dilemma in terms of display support. One could either wait until the game is finalized; or one could seek a flexible display system, capable of supporting a variety of manual games. The Space Wargame elective preferred the latter choice (94:--). This choice assumes that display support will assist the testing and development of the manual game. The game and its associated displays would then form the foundation of the computer-based space game if a computer game is deemed necessary by researchers next year.

Defining the information needs of the game-independent space researcher is more formidable than determining the information needs of the wargame researcher. The problem here is one of variety. Researchers could be involved in a great variety of space-related research for which display support is needed. For example, one might want to examine the benefits in terms of strategies and operational flexibility of an enhanced satellite propulsion system. The goal would be to determine how much of an improvement in propulsion capabilities is needed to improve operational performance. One might want to "...quantify trade-offs between the performance of surveillance, C3, and weapon elements of a space-based laser system capable of performing {BMD}" (52:1). Actually, one would not necessarily study this topic since the General Research Corporation has already performed such a study for the Air Force Rome Air Development Center (RADC). However, a student might find a follow-on subject to pursue under RADC sponsorship while attending AWC or ACSC. One could look at the timing relationship of various threats to space systems with a goal of discovering strategies for space employment which minimize those threats (88:--). One could take this topic one step further and look into the effects of various survivability measures (51:37,38-40,50) such as mobile ground stations or maneuvering satellites. There are any number of possibilities, and the potential topics are quite diverse.

Just as in the case of developing a wargame, coverage information and timing relationships are likely to be of interest. The key need here is for flexibility. Display support to researchers ought to be flexible so that a large number of issues can be studied. The coverage and timing capabilities of any display support system must be extensive. To support the widest possible audience, one must be able to depict space-to-earth, space-to-space, and earth-to-space scenes. One should be able to calculate, and then view the length of time it takes the scenes to occur or recur, as in the case of orbit motion. One needs to freeze motion to a still view, and then step through the orbit to view subsequent effects. If the author was researching the topics described above, instantaneous coverage plots as well as coverage plots over time would be of interest. In the author's opinion, a robust capability to display the information in Table 7 would greatly assist space researchers at Air University.

ATTRIBUTE	DESCRIPTION
Satellites	One satellite case, many satellites combined
Views	Space-to-Earth (coverage) Space-to-Space Earth-to-Space
Volume-of-Interest	Orbit selectable anywhere from lowest earth orbit to beyond geosynchronous altitude. View volume between 2 satellites, earth and satellite, satellite and earth. Provide projections on earth.
Timing	Satellite motion and earth rotation. Freeze motion. Satellite orbit path or trace.

TABLE 7 - Generalized Information Needs for Researchers

Before proceeding one should address the question: so what? What if we ignore this audience in terms of displays and do nothing? What do we lose, if anything? The answer is: efficiency and creativity (81:--). Space motion and space capabilities are not intuitive. It is difficult to visualize the sequence of events, and understand relationships, without displays. Researchers become less efficient when they must rely solely on numbers. Studies which involve orbital motion can require review of a great many numbers. Computer-generated simulations of orbit motion can speed up the process, and provide views that otherwise would not be possible. For example, a researcher at the Aerospace Research Institute (ARI) is working on a paper describing the utility of a stable, geosynchronous (24-hour), elliptical orbit (79:--). It is difficult to imagine what the orbit looks like without sequenced graphics showing the satellite, the earth, and the view from the satellite to the earth as each moves. Computer provided displays and simulations relieve the researcher from the burden of generating, changing, reviewing, and changing again, large lists of numbers. Graphics have increased efficiency by one-third to one-half in other applications (63:v,19-20).

The creativity aspect of this information requirement implies that some research projects will never be started if the right tools are not available. Some scenes may be vital to understanding an issue; and unless they can be viewed via a simulation, they cannot be accomplished. For example, if one was studying the pointing accuracy constraints on space-based BMD, documents may dictate accuracies of a fraction of a degree. These are just numbers until one simulates a space-based weapons platform in orbit. One must simulate a multiple ICBM raid, step through small time increments and simulate a laser firing at one of the warheads. Only by freezing the activity, looking at the beam with an assumed beamwidth, and then "blowing up the scene" at the ICBM end; does one really see why the pointing accuracy is so important. Unfortunately, these arguments for efficiency and creativity are impossible to quantify. The answer to the question: "what do we lose if we do nothing?" is unknown. And we will never know the answer if we do nothing. Information and display needs for space researchers are completely subjective.

The information and display needs of space researchers are subjective because of the conjectural nature of the work. The requirements to support space wargame development and a variety of possible strategic studies imply a need for a flexible capability. Status, coverage and timing information highlights the types of data usually required.

SUMMARY OF INFORMATION NEEDS

The information needs of the three audiences of students and researchers may not necessarily be distinct. Where possible, one should strive to combine the information needs into single displays or display capabilities in order to avoid duplication of effort. This summary will look at the three audiences' information needs and lay them side by side. In the next chapter, the author combines these various needs to develop display needs.

When introducing space in the curricula, both the basic principles of spaceflight and examples of often-used orbits ought to be illustrated. Students need to review how satellites are launched, and they should understand that the end of launch determines the orbit. The characteristics of orbits in general, i.e. their repetitive motion around the earth and speed changes should be presented. The students should also understand that earth plots of satellite motion involve both the satellite's motion and the earth's rotation. Sample low, medium and high earth orbits should be illustrated along with the advantages of each. With this information, the students will be better prepared to continue their studies of space systems and issues.

When playing CRES wargames, the students need a variety of information depending upon the game and space system being played. If weather systems are modelled, then weather data should be provided to the players. If the scenario calls for the use of RED space threats, then the weather data would be degraded in quantity, quality or timeliness. Similar modelling should be provided for the other types of satellites where appropriate. Status displays of some satellite constellations will be needed. Coverage plots and time data will be required when that information is available to the real world counterpart of the players. The Strategic Nuclear Exchange exercise appears to have more opportunities to model space systems than the other games.

The third audience's information needs are more difficult to describe. Two goals for space research are: development of a space wargame; and independent, space strategy research. To support these activities, a flexible capability to view one or more satellites, their motions, and views of earth are needed. Various geometric views would be needed, as well as the capability to step through time and see the views change. Some method of aggregating this data is needed. Flexibility is important because of the difficulty of predicting the various research projects which could be undertaken.

The three audiences have different information needs. If the researchers' needs are met through the development of a simulation tool, then that same capability may fulfill the information needs of the introductory audience. Participants in CRES wargames will have some unique, space-related information needs. Based on all these needs, the analysis proceeds by examining methods of displaying the information.

Chapter Four

DISPLAYS

Recently developed technology in display devices provides new opportunities to get the space message across to students at Air University. Space activities occur in the three-dimensional space around the earth. The relatively simple motions of satellites and orbits can be viewed most efficiently by looking at three-dimensional representations of those motions (84:156). Moreover, recent advances in computer graphics afford one the opportunity to display such three-dimensional views relatively easily. Not only exotic display devices but the plethora of devices associated with small personal computers give Air University the opportunity to display scenes and teach concepts not previously possible. Depending upon the information to be displayed and the devices available, we may be able to more efficiently impart information on the basic rules of spacecraft motion, the utility of space systems, and the doctrines for space than may have been possible five years ago.

This chapter will answer the questions: what should be displayed to support the space curriculum, to support the use of space systems in wargames, and to support the space strategy researcher? The analysis begins by looking at recent developments in computer graphics with a review of important display parameters. Different display systems use different combinations of the display parameters, and examples will be cited. Feasible display capabilities are compared to the space wargame information needs to produce display needs. An existing display system will be described. Finally, a candidate set of displays will be suggested for future use at Air University.

COMPUTER GRAPHICS

Computers have used and produced specialized graphics since the mid-1950's when MIT produced plots from screen displays, and the Air Force's SAGE air defense system first used light pens in a production system (2:18). Research on various graphics devices continued in the 1960's and 1970's (2:18), but stalled in the

1970's due to problems with cost and system design (2:19). In the late 1960's and the 1970's, these problems diminished with the invention of the direct-view storage tube; with the miniaturization and specialization of computer memory; and with improvements in computer software systems (2:19-21). The experience and refinements developed in the last ten years have led to "...the most important mechanized means of producing and reproducing pictures since the invention of photography and television" (2:5).

Computers are used to process and manipulate information. Computer graphics are concerned with selected information.

> ...computer graphics is the creation, storage, and manipulation of models of objects and their pictures via computer. Interactive computer graphics is the important case where the user dynamically controls the pictures' content, format, size or colors on a display surface by means of interaction devices such as a keyboard, level or joystick (2:3).

Based on work done over the past few years, a building block approach is usually taken when putting together an interactive computer graphics system. The building blocks consist of a computer, a display processing unit, a display device, a user input device(s), and a plotter/printer combination (2:93). Figure 9 illustrates the typical arrangement of the building blocks. The displays depict alphanumeric characters and/or pictures. The pictures can be either two-dimensional or three-

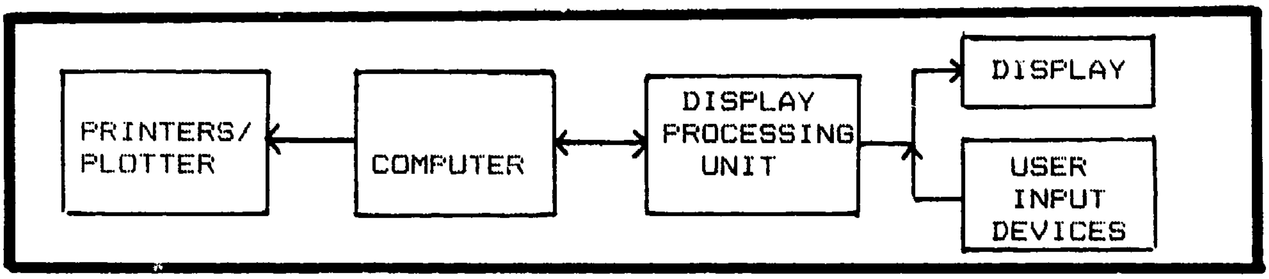

Figure 9 -- TYPICAL INTERACTIVE COMPUTER GRAPHICS SYSTEM

dimensional. Although only expensive aircraft simulation systems have approached the goal, the long-term objective of these systems is "...to produce computer generated images which are so realistic that the observer believes the image to be that of a real object rather than of a synthetic object..." (2:539). As will be seen later, some systems come very close to the goal, while other systems although further away, are very cheap. Before looking at examples, we turn next to an examination of the important attributes of these systems.

There are a variety of display system attributes worth discussing. Input and hard copy devices could be reviewed for there are many possibilities in each case. This analysis, however, will concentrate on the display device and the processing unit. In the author's opinion, these are the most important elements of a system in terms of its display capabilities. Table 8 lists the author's categorization of these parameters or attributes, based on the sources cited for each parameter. As the table indicates, alphanumeric characteristics apply to two- and three-dimensional displays, and two-dimensional attributes apply to three-dimensional displays. The next few paragraphs describe each attribute.

Alphanumeric displays	Two-dimensional displays	Three-dimensional displays
-Raster -Resolution -Number of Colors -Formats -Brightness	-Vector or Raster -Translation -Rotation -Scaling and Zoom -Shearing -Contrast	-Depth perception: -Perspective Projection -Intensity Depth Cueing -Hidden Surface Removal -Shadowing -Static versus Dynamic -Stereoscopic View

TABLE 8 - Important Display Parameters

Alphanumeric displays use an electronic beam to raster back and forth across the display screen. The time it takes to complete a screen depends on the speed of the electron gun and the resolution of the display. The resolution is the number of rows and columns of dots used to build the displays (9:1). The greater the resolution, the more detail that can be displayed. Most display devices are monochromatic, i.e. use only one color, while others are capable of displaying multiple colors (2:235). The resolution and colors are often used to describe different display devices available for a given computer. Thus, the IBM personal computer has four display devices available: high resolution, 640 x 200 - single-color; medium resolution, 320 x 200 - four colors; 80 column text, 80 x 25 - sixteen colors; and finally, 40 column text, 40 x 25 - sixteen colors (9:1). Alphanumeric data can be displayed in various formats, i.e. sizes and locations on the screen; and different brightnesses can be used to highlight selected data. Alphanumeric displays are the simplest and cheapest to operate.

When pictures and graphs are needed, two-dimensional displays are used. The two main types of displays used here are raster or vector. When a high resolution screen is used, raster displays sometimes cannot completely draw the screen because the beginning of the drawing fades before the screen is fully drawn. This is called flicker (49:7). The system design can mitigate against flicker through the use of two alternating memory groups to draw and display consecutive scenes (9:202), but this requires more computer memory. Vector displays have a special purpose processor that automatically draws lines between two endpoints. Vector displays are faster and usually more expensive than raster machines. The two broad categories of picture display hardware are raster machines and vector machines.

There are a number of attributes that enhance the display of pictures. Different display systems mix and match these attributes. Many attributes are modelled using software in the computer system. Translation is the movement of the object to different areas of the screen. Rotation is the twisting of an object or a scene about an axis (9:68). A translation and a rotation of a scene is the same as moving the viewer's perspective in the opposite direction (9:103-104). The computer's ability to manipulate data enables one to stretch objects in various ways. Scaling is stretching or compacting an object along a single axis (9:39). Shearing is stretching or compacting along each axis a different amount (9:99). Zooming involves lengthening or shortening an object by an equal amount along each axis. When black and white scenes are used, contrast enables one to differentiate shades of gray. Two-dimensional computer displays provide a great deal of flexibility when creating and changing (9:203) graphs, schematics and pictures; and these displays are available on both small and large computers.

Some scenes are enhanced when viewed three-dimensionally, but it is difficult to depict three-dimensional scenes on a two-dimensional screen. The major challenge is to give the viewer the impression of depth (9:62,164). One of the most important techniques used to give the impression of depth is through the projection of linear perspective (9:62-64; 2:542-543). Figure 10 illustrates the technique (9:64). Linear perspective is one of three psychological depth cues, the others are: overlap, and shading and shadowing. There are physiological depth cues as well, but this analysis will highlight only some of these techniques to indicate depth (9:164). Speed and memory capabilities of the computer are sometimes very important for three-dimensional displays. When the different methods to enhance depth perception are added to the computer graphics system, the processing required to display a scene becomes more complicated.

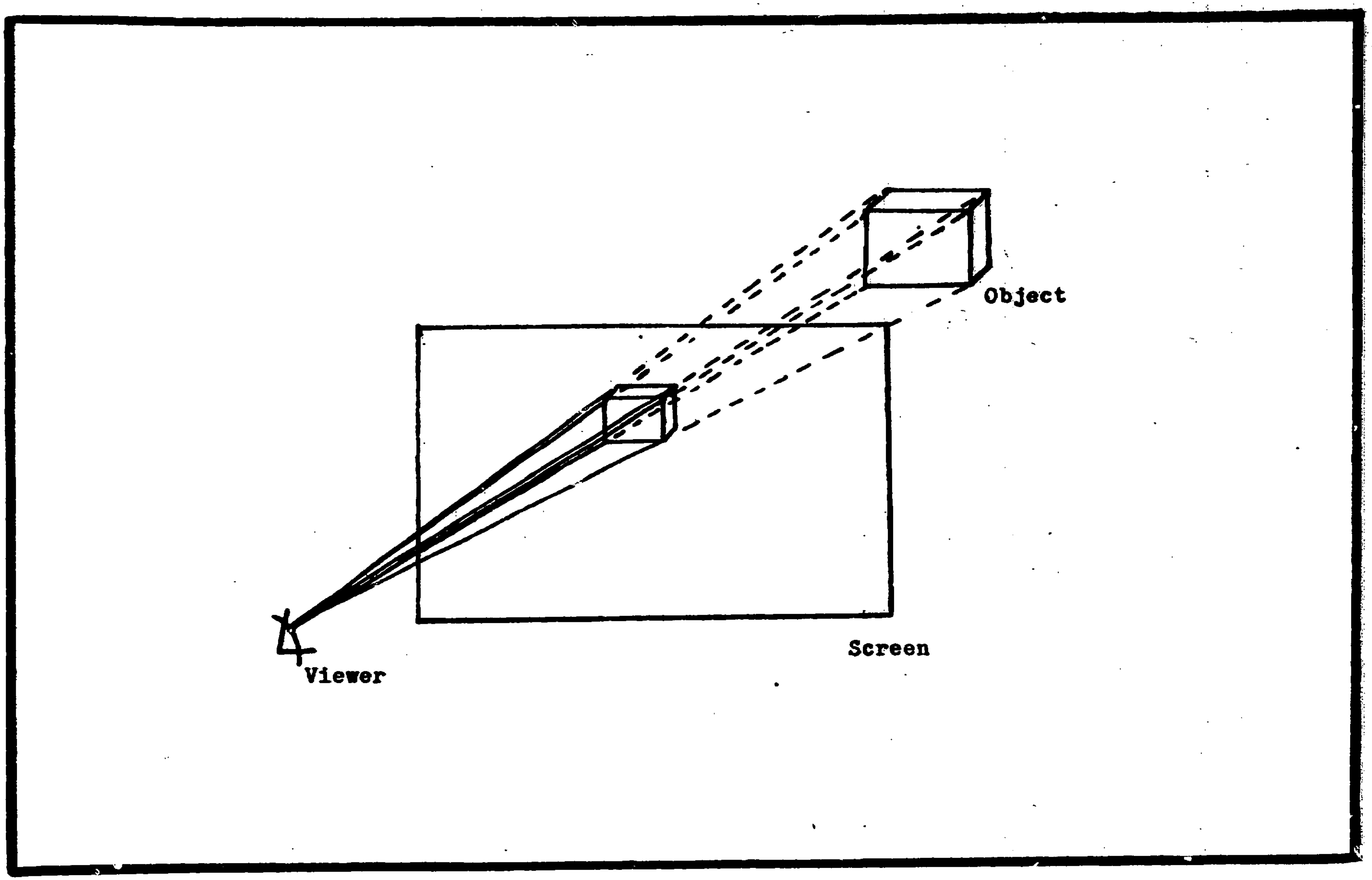

Figure 10 – LINEAR PERSPECTIVE PROJECTION

Using the parameters listed in Table 8, those additional parameters which enhance depth perception will be reviewed. Depth perception can be enhanced by varying the brightness intensity of the scene. Nearer objects are brighter, farther objects are darker (2:235,542-543). By clipping the back or sides of a scene, one gives the viewer the impression of being closer to the object (2:542-543; 9:107). This is especially powerful after zooming in on an object (2:235; 49:12). When one projects an object onto the screen, one can project it as if it is transparent so that the viewer sees all the boundary surfaces. This is called a wire drawing, and it can sometimes be confusing. Depth perception is enhanced when the back boundaries are hidden from view by the solid boundaries of the front surfaces (49:32; 2:392-393,542-543; 32:216). A more elaborate mechanism involves varying the brightness intensity to indicate shadows from an assumed light source. There are a variety of methods to model shadowing (2:575-590; 6:86-91). The various ways of modelling depth can be combined for each computer graphics system.

There are also methods for the creation of stereoscopic images, for example, of aircraft radar returns (51:38-8). These techniques have been used to obtain stereoscopic images on personal computers (9:163-192), but the author feels that stereoscopic images would not be needed for the application here. Stereoscopic viewing requires some modification of computer graphics screens to separate the left eye view from the right eye view. In the author's opinion, combinations of the other depth perception cues model three-dimensional scenes adequately for the applications envisioned. Moreover, the special purpose modifications necessary to obtain stereo views would be cumbersome to implement especially for the general student audience. This would be the case especially for the Introductory and CRES wargaming audiences. Stereoscopic modelling may be useful for the research audience; but once again, the author believes that combinations of other depth perception cues are adequate for this audience as well.

The final parameter considered concerns the use of static versus dynamic (animated) (80:--) displays. "While static pictures are often a good means of communicating information, dynamically varying pictures are even better. This is especially true when one needs to visualize time-varying phenomena" (2:5). This will be the case for space displays since the satellite is always moving. Three-dimensional viewing creates special challenges when using computers. There are a variety of techniques used to enhance depth perception; but as one adds to a computer system's repertoire of techniques, one increases the need for memory and computer speed in order to keep the scene(s) looking natural.

There are a large number of computer graphics display systems available to fill users' needs. The large, fast machines have been developed for computer-aided design (CAD), computer-aided engineering (CAE), or computer-aided manufacturing (CAM) applications. These applications have spurred research into the mathematics necessary to improve the displays. For example, fractal geometry was developed in connection with display research, and it helps create realistic displays of natural phenomena like coastlines and mountains (6:125-127). There is much work to be done because fast, high resolution, three-dimensional displays are both difficult and expensive to obtain. Special techniques such as using assembly language programs are used to speed up processing (9:123). These programs, however, are more difficult to create. Systems can become expensive when precision and resolution are needed for the application. Greater precision implies using more display parameters to approximate realistic views. Higher resolution implies more memory, and thus more display processing to be done in a given unit of time. All of this drives up the cost of the computer graphics system, but smaller systems can use some display parameters with the resultant loss of performance (45:46). A great variety of choices are available.

Air University has, or soon will have, a number of display devices available for use with space displays. Each seminar will have a Zenith 158 computer with 640K (thousand) bytes of random access memory, dual floppy disks and a 10M (million) bytes hard disk system. The computer will have two display devices available: a 13-inch color monitor and a 25-inch Zenith television monitor. The television can display information from the computer as well as from tapes and TV cameras. Some color monitors will have a resolution of 640 x 400 with the installation of a graphics board in the computers. Most of the color monitors will have a resolution of 320 x 200 (93:--). The computers will have both a keyboard and a mouse device for use with the graphics system. A dot matrix printer will provide hard copy output. The Z-158 computer and the 13-inch color graphics monitor will be the main terminal system for CRES. The terminals in the Wargaming Center are connected to the large CYBER 175 computers on which the computational modelling is done. The Air Force Wargaming Center computers will not be initially connected to the seminar computers, but they could be connected at a later date with the purchase of the necessary communications devices (93:--). Wargames will be conducted within the Center using the same type terminals available in the seminar rooms. There is also a JTLS/MAPS system used in the Wargaming Center to simulate real-world command and control flows (91:--). The color graphics monitor of the Z-158 computer will be the primary available display device.

Computer graphics provide for the display of alphanumeric data, two-dimensional pictures and three-dimensional pictures. Interactive computer graphics are getting closer and closer to the goal of real-life displays, but there is a long way to go. Air University will be using a graphics terminal in both the seminars and the Wargaming Center. The analysis looks at other examples of computer graphics systems to highlight the possibilities of meeting the space-related display needs in the future.

EXAMPLES OF DISPLAY SYSTEMS

Computer graphics displays are used in a variety of applications. Three systems are described to give the reader the flavor of their use. The disussion begins with a description of the need for both two-dimensional and three-dimensional displays. One education system and two military systems will be examined.

Before examining the examples, the study first looks at the need for three-dimensional displays. Are these necessary? The answer is yes. Satellite motion is inherently three-dimensional. Except for the case where the satellite is in the equatorial phase (see Figure 11), the satellite travels in an orbit plane different than the plane of the earth's rotation (see Figure 12). The three-dimensional views can help immensely, especially for the introductory and research audience. It should be used judiciously in the wargames as well. This is not to deny the use of alphanumeric or two-dimensional displays. Some scenes are enhanced when depicted in two-dimensions. Figure 13 provides a cross plane look at an LEO. Only from such a display can one appreciate how low an LEO is with respect to the earth's radius (83:--). Two- and three-dimensional displays can help one intuitively understand the motions of spaceflight, just as most of us have an intuitive motion of air flight (80:--). Thus both two- and three-dimensional displays, as well as alphanumeric data to label items and display orbit parameters, are needed. A computer graphics system displaying the different scenes can assist "our well-developed two- and three-dimensionally oriented eye-brain pattern recognition mechanism..." (2:5). This conclusion on the need for both two- and three-dimensional displays has been reached before, and the next few paragraphs will illustrate three examples.

In an article (42:178) on the use of computer graphics in colleges, a writer for BYTE magazine wrote of the following example.

> The biology course makes extensive use of Intermedia's graphics capabilities. Students (and professional biologists) have had difficulty visualizing a three-dimensional object, such as a cell, based on two-dimensional drawings. A student who can call up a digitized electron micrograph of the cell in question, with 3-D models that can rotate and change scale and with links to 2-D drawings, has a better chance of forming an accurate mental picture of the cell. In addition, after following links back and forth between 2-D and 3-D representations, the student is better able to analyze the 2-D drawings in texts and journals and has a better feel for how they would look in three dimensions.

Three-dimensional graphics aid the education process.

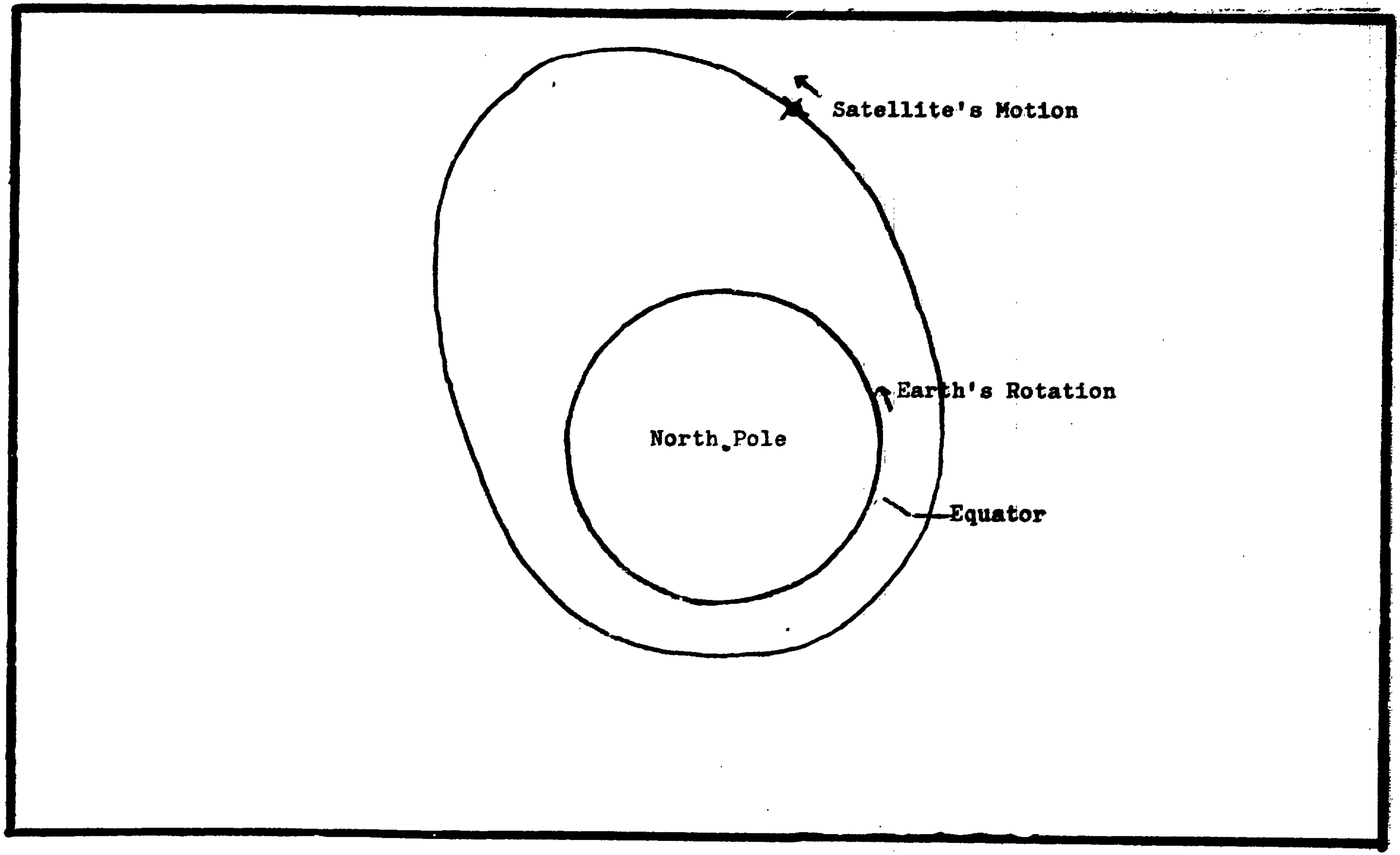

Figure 11 – POLAR VIEW OF AN LEO IN THE EQUATORIAL PLANE

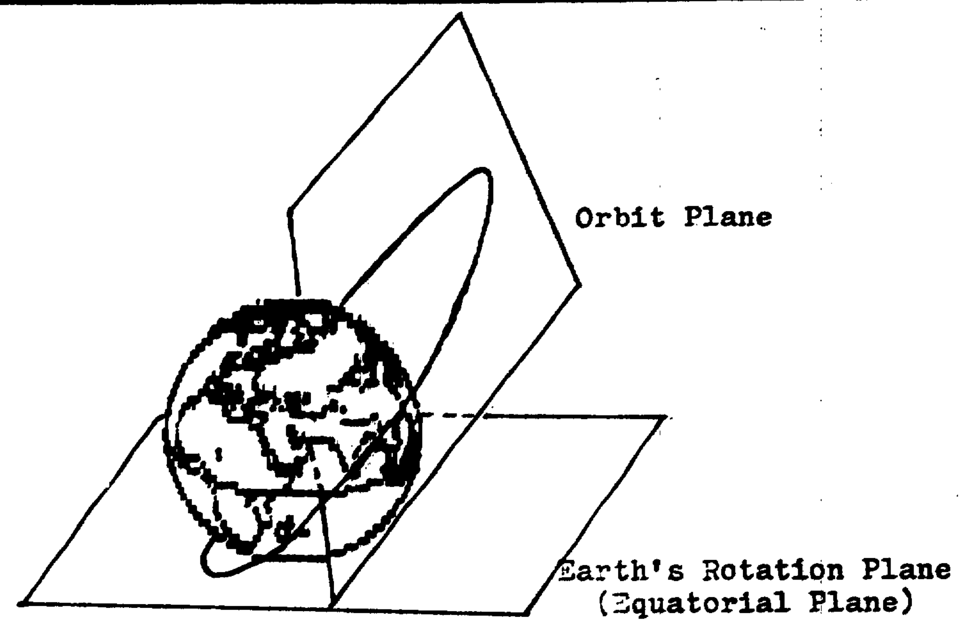

Figure 12 – ORBIT PLANE

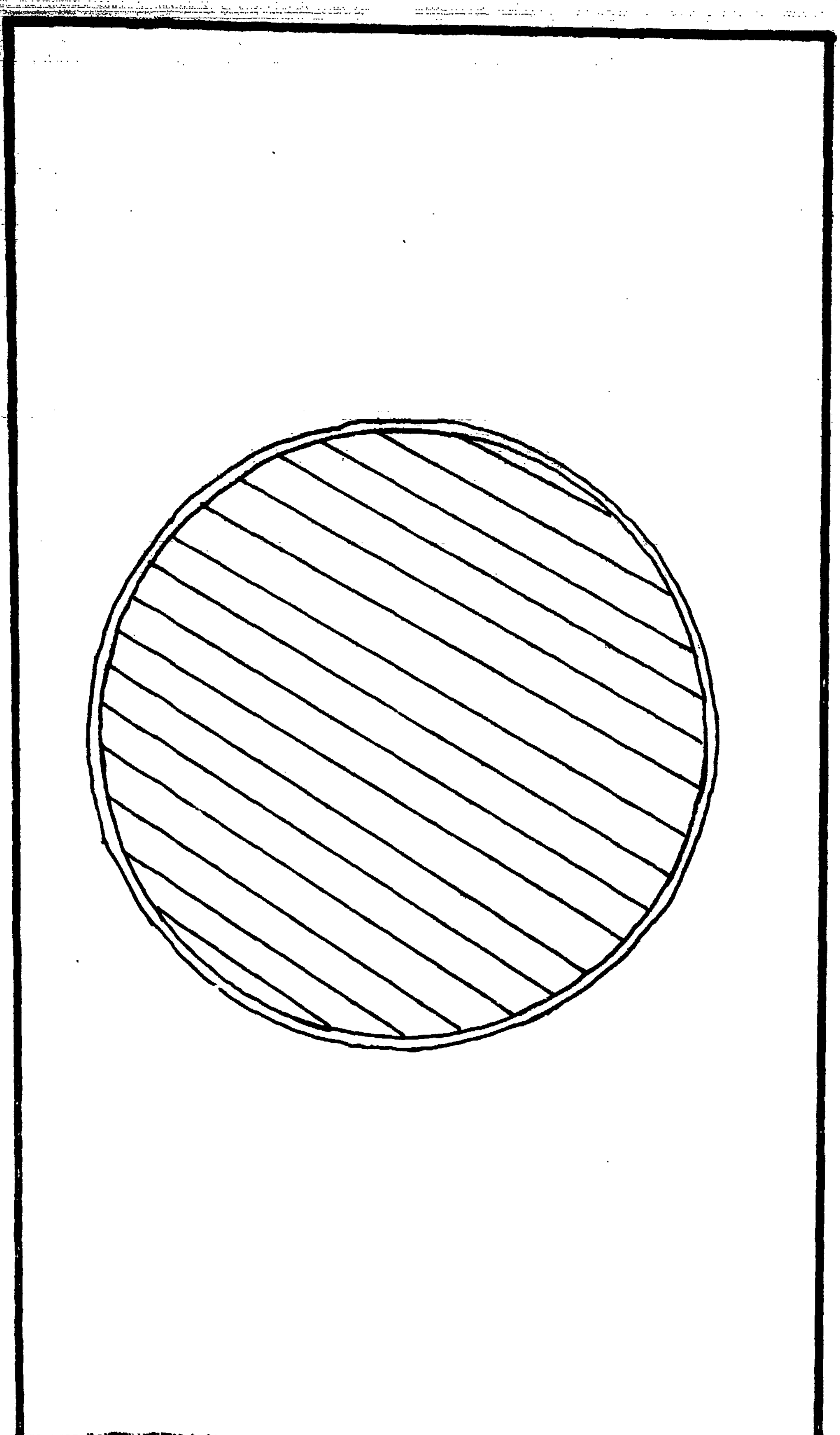

Figure 13 – CROSS PLANE VIEW OF A LOW EARTH ORBIT

In a study on the need for picture displays in the F-15 for the Air Force Flight Dynamics Laboratory (50:--), Jauer and Quinn noted the need for both two-dimensional and three-dimensional displays. Surface threats were most appropriately displayed on a two-dimensional scene looking down on the area. Overlays on the same scene could be used to show additional data, like weather or terrain. Three-dimensional displays were then used to show "safe tunnels" (59:24) through which the threat radars are masked by the terrain (50:22-24). This was called a flight channel display (50:6-7). Three-dimensional displays were also used to depict terrain from different viewpoints. Jauer and Quinn noted that color sometimes helped distinguish items and added realism to the displays (50:50). They also noted that dynamic displays are very helpful in some applications, but too much dynamism can be confusing (50:118). Thus there is a need for both static and dynamic displays.

In the development of a graphics simulator for weapons controllers, Asch, et. al. (49:--) concluded that both two-dimensional and three-dimensional displays were needed. "Students need to be shown both the two-dimensional and three-dimensional aspects of intercept geometry, tactics and procedures" (49:4). While the Aerial Combat Maneuvering Instrumentation (ACMI) system provides high quality three-dimensional dynamic views for pilot training (16:159-167; 49:3), Asch, et. al. were tasked to provide similar training to weapons controllers (49:3). Using an AYDIN Controls Inc. Model 5216 graphics system with a resolution of 1024 x 1024, they developed a simulator for use in training (49:5). They noted that three-dimensional displays were most helpful; but they also noted that two, two-dimensional displays (top and side views of intercept geometry) (see Figure 14) were sometimes preferable (49:36). Through three examples we see that if the problem under consideration requires viewing a three-dimensional volume, then both two- and three-dimensional displays are necessary to fully visualize the scene.

DISPLAY NEEDS

This section is designed to take the three audiences' information needs, compare them to the computer graphics capabilities described in the previous section to develop space-related display needs. A matrix indicating the various needs of the different audiences is provided. The section will end with a review of an existing space display system.

The three audiences for space displays have different display requirements based on their information needs. In the author's opinion, Table 9 provides an overview of their different needs. The next few paragraphs will explore these needs in more detail.

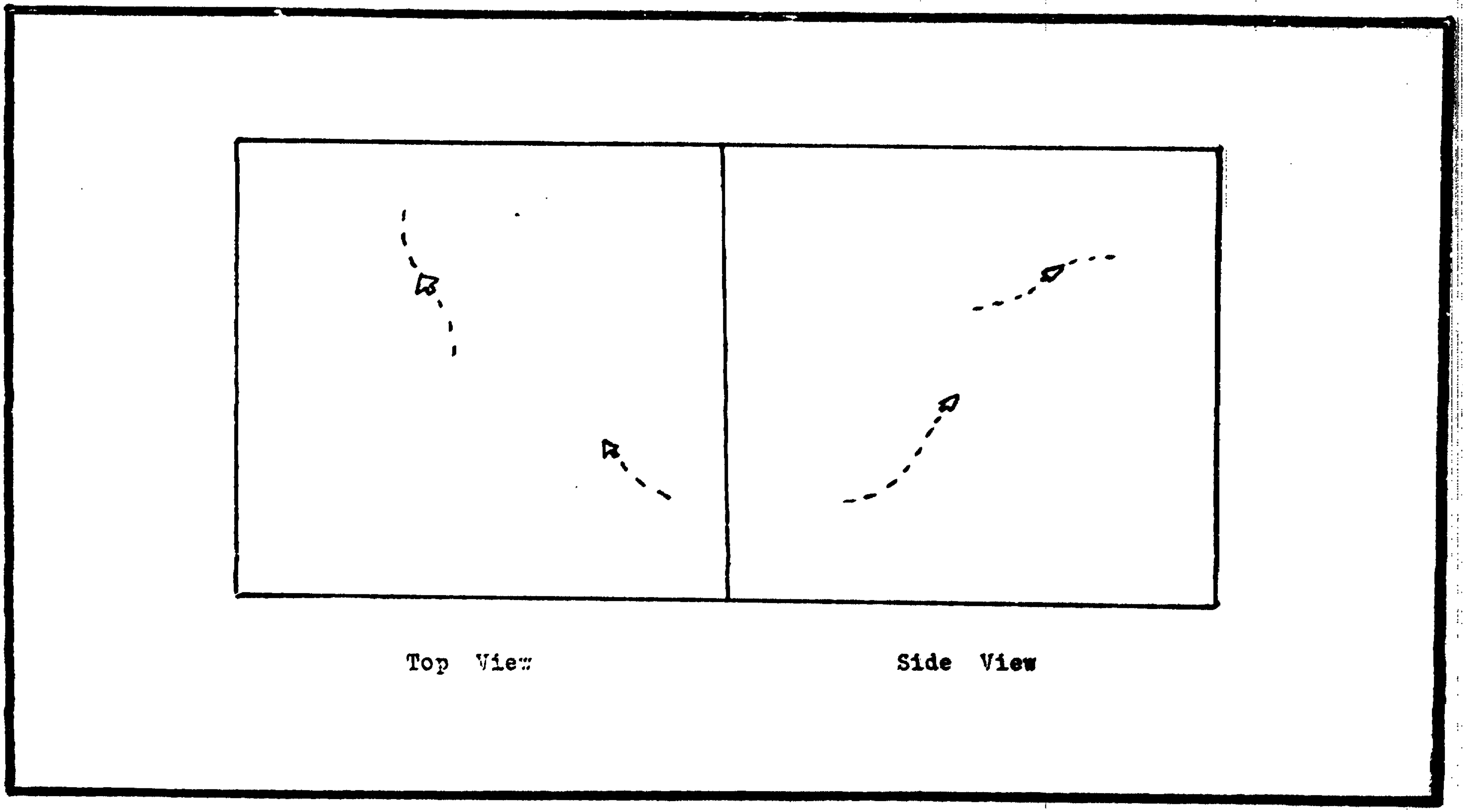

Figure 14 – FLIGHT PATH PROJECTIONS

	Introductory	Wargame	Research
A/N		X	X
2D	X	X	X
3D	X		X

TABLE 9 - Overview of Audience Display Needs

The introductory audience includes both the students, and the faculty who develop the curricula. The faculty needs to display the fundamental principles of spaceflight described in Table 3, and they need the ability to change the displays. The essential requirement is to depict both the satellite's and the earth's motions. Static displays help immensely, but dynamic (animated) (80:--) displays are much more influential in the author's opinion. Both two-dimensional and three-dimensional displays are needed. There are two preferred perspectives. First, a view from beyond the zone of interest (either above or to the side) shows both the earth and the satellite (82:--). Second, the view from the satellite to the earth should be displayed (82:--). In the latter case, one ought to have the option of restricting the view to some angle about the ground subpoint, as opposed to viewing the whole earth. An ability to depict these views for LEO's, MEO's and HEO's is needed.

By dynamically generating the orbit traces, or the views from the satellite to the earth, one can more readily distinguish changes. Thus multiple perspectives in both two- and three-dimensional displays will meet the information needs. In the ballistic analogy example, note that the static display of Figure 4 employs a perspective projection with hidden surface removal. If we zoomed in on this scene and employed depth clipping, we would have a better perception of depth. One could create this scene dynamically by tracing out the flight paths sequentially from the shortest range to the orbit injection case. Dynamic displays are proposed because they can quickly get the message across. For example, to teach someone that the lower you are, the faster you fly; one could start with the LEO depicted in Figure 13. Then the scene changes viewpoint to one of the satellites looking at the horizon-to-horizon view of the earth (82:--). Then the view moves as the satellite moves in its orbit (82:--). The viewer sees the earth pass underneath at a certain rate. The display must have sufficient resolution to describe recognizable continental boundaries. Then the scene switches to a higher circular orbit with similar orbit parameters. The viewer will note two things: first, one can "see" more of the earth than in the previous displays; and second, the rate at which the earth passes underneath is less (82:--). The higher you go, the slower you go. If one models the earth's rotation at the same time, then the observer sees that only two motions (the satellite orbit and the earth's rotation) produce different satellite views for subsequent revolutions. These scenes are difficult to imagine unless one sees them; and an attempt will be made to display a case similar to the one cited above, in the next section. The efficiencies obtained may come at some expense. For example, on a project that the author worked on, an interactive computer graphics system was developed with satellite-to-earth views. The system, which employed a Chromatics CG system (512 x 512 resolution, 16 million colors and shades) (86:--) used map boundaries in the views. As greater levels of Zoom were required, the amount of memory was expanded to 2 megabytes to increase the speed of the display processing. The latest Chromatics CX system is very fast. It provides a resolution of 1536 x 1132 using 8 megabytes of memory (86:--). As the resolution and processing speed of computer graphics machines increases, one's ability to produce realistic animated scenes is enhanced. These examples highlight the efficiencies obtained with dynamic displays.

Since each seminar will have a Z-158 computer, some display needs can be met using this machine. This will be true for static displays. For example, the background charts in this paper were produced by Major Al Glock, a fellow student at ACSC, on an IBM PC. Personal computers will be limited in their ability to produce dynamic displays. As a minimum, the ability to translate, rotate, and zoom scenes will be needed in addition to the requirement to show dynamic motion. True animated motion as described above will require a faster computer than the Z-158 computer.

For the CRES wargaming audience, the display needs are simpler. They need information from the satellites, and data on satellite status. This is text data and can be provided by an alphanumeric system, or by whatever system simulates communications devices in the game. In the Strategic Nuclear Exchange (SNE) game, the player who simulates CINCSPACE needs the status displays described by Figures 7, 8, and Table 6. This is appropriate since these are among the new displays that will soon be used by the SPACECOM staff (42:--). Note that Figure 7 disagrees with Table 9 in that Figure 7 represents a three-dimensional display. This display is static and could be changed to a two-dimensional display, but Figure 7 is preferred because it gives a hint of the satellite-to-earth coverage. Compare Figure 8 to its two-dimensional counterpart --Figure 15. Coverage charts will be required in the SNE exercise, and possibly in the other exercises. Figure 5 is an example. All display requirements for the CRES user are for static displays only. Three-dimensional displays are optional, but some two-dimensional status displays and coverage plots are required. The Z-158 computer and its color monitor will be more than adequate to support space play in the CRES wargame.

The research audience's diverse need for display support makes meeting this need more challenging. The wargame researcher will want to try a display, use it in a game, and then change the

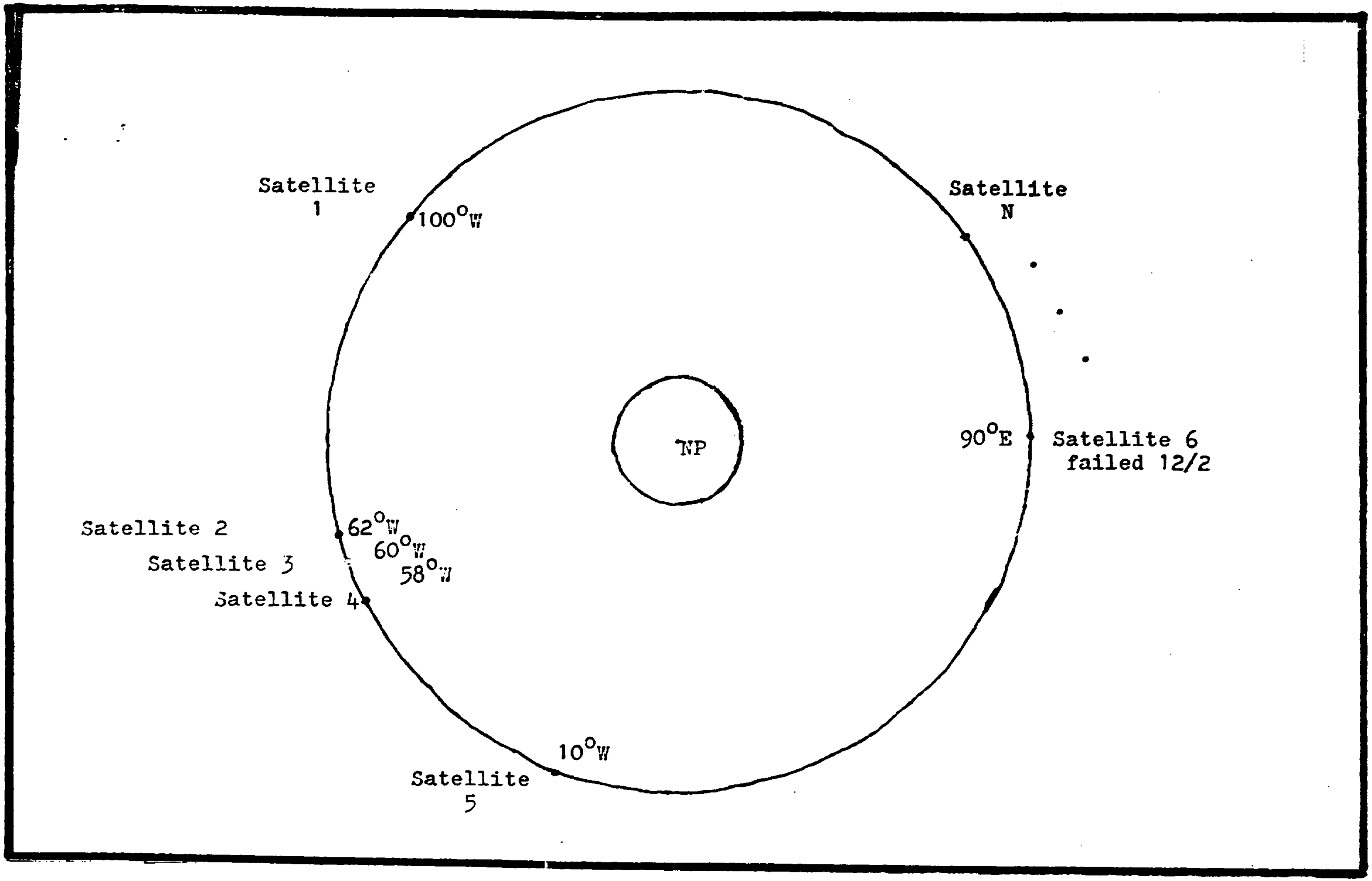

Figure 15 – GEOSTATIONARY SATELLITE STATUS

display. To enhance the manual game, one would want to try a number of alternative displays during the testing of a specific manual game. The strategy researcher should have the ability to alter single variables and see the effect of the change (10:46-47). This implies the use of an interactive computer graphics system. It will be important to view the displays described above for the introductory audience. In addition, earth-to-satellite views, satellite-to-satellite views, and special volume views will be of interest. For the greatest flexibility, the researcher needs the ability to adjust the scale of time--to speed it up, slow it down, or freeze it. An ability to view multiple scenes simultaneously will be very useful. An example could involve an orbit display and the alphanumeric parameters in a window off to the side (83:--).

Another example of space research display needs could involve either the wargamer or the strategic researcher. They might be interested in simulating a BMD engagement. A set of SDI satellites might be assumed, and an ICBM raid simulated. By modelling timing constraints, one could simulate the engagement, determining how many ICBM's were intercepted, and how many were not (69:--). In order to model timing constraints, a dynamic display is needed. As mentioned earlier, one might freeze the display and examine the beam widths from the satellite to the ICBM, or the coverage circles to ground station if the satellite needs to be tethered to a ground station. Figure 16 illustrates a static display of the engagement. One might translate, rotate and zoom in on the volume of interest indicated in the figure. Earth-to-satellite views would be of interest to show how many BLUE satellites are in view of the ground station simultaneously, or over time (82:--). The variety of displays possible for this audience requires a comprehensive and flexible display system.

Any computer system designed to meet these needs will require speed and a great deal of memory to handle the dynamic (animated) displays of motion. Any interactive computer graphics system capable of satisfying the needs of the research audience can be used to meet the needs of the introductory audience if the display can be seen in the seminar rooms. This can be accomplished by setting up the display on the computer, and then taping it, possibly in conjunction with a presentation by a faculty member. The capability to display such a system would be useful in conjunction with a space elective at the AWC, the ACSC or both (81:--). It would be especially useful if this system could be interactive, i.e. if changes could be initiated from the seminars to wherever the interactive display computer system resides. There exist devices which link the red, green, blue signals from the interactive computer to a videotape recorder or a television. The LENCO PCE-462 color encoder and the LENCO CSC-7100 Synchronization Generator were used in the weapons controller training system (49:10). The Z-158 computers in the seminars will have this capability (93:--). The hardware and software implications of the researcher's requirements are formidable.

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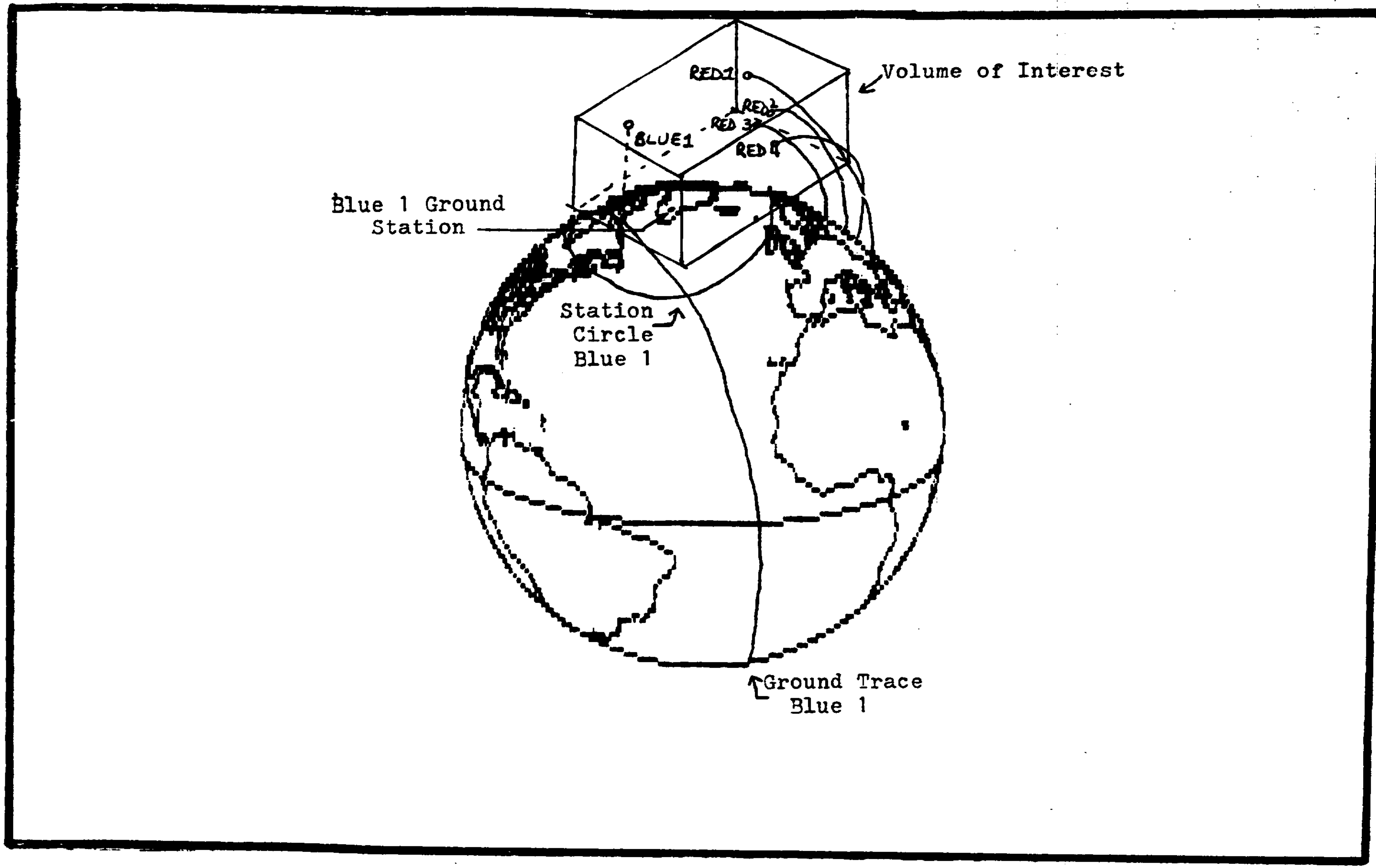

Figure 16 – BMD ENGAGEMENT SCENARIO

Table 10 summarizes the implications of these display needs in terms of display parameters. The reader will note that the selection of certain parameters is arbitrary. The table represents the author's opinion of the more important parameters to meet the subject information needs. Certain row headings have been deleted. The row heading of "Raster," "Shearing," "Contrast," "Shadowing," and "Stereoscopic" from Table 8 have been arbitrarily dropped here by the author. From the table, one notes that in the author's opinion, the display needs for the introduction and research audience are similar, while the display needs of the CRES wargamer are quite different.

The Satellite Orbit Analysis Package (SOAP) (82:--) is both the source of many ideas for displays presented earlier, and the solution to fulfilling many of the display needs. This appears to be a self-fulfilling premise. Actually it is not. The author had hypothesized many of the displays prior to starting the paper, but then discovered that most were available in SOAP.

Display Parameters	The Audiences: Introductory	CRES Wargamers	Researchers
A/N			
-Resolution	H	L	H
-Number of Colors	1	1	3 or more
-Formats	-	X	X
-Brightness	O	O	X
2-D			
-Vector or Raster	V	R	V
-Translation	X	O	X
-Rotation	X	O	X
-Scaling and Zoom	X	O	X
3-D			
-Perspective Projection	X	O	X
-Intensity Depth Cueing	O	-	X
-Depth Clipping	O	O	X
-Hidden Surface Removal	X	O	X
-Static or Dynamic	D	S	D

LEGEND: L - Low, H - High; X - Needed, O - Optional, - - Not Applicable; V - Vector, R - Raster; S - Static, D - Dynamic

TABLE 10 - Implied Display Parameters

SOAP was developed to support the Global Positioning System Joint Program Office, and an overview of its capabilities is provided in Appendix C. SOAP consists of both a powerful interactive computer graphic display system and an extensive set of software. The computer is a combination of a VAX 11/785 and a PS 350 computer graphics system manufactured by Evans and Sutherland Corporation. Vax computers are manufactured by Digital Equipment Corporation. The PS 350 has both vector and raster options (95:--). SOAP was designed on the Vector machine. It has a resolution of 8192 x 8192 on a 19-inch (10.5 x 10.5 useable) screen using 1,800 colors and 64 intensity values. The graphics display computer possesses 4 megabytes of dual ported memory. The resolution is particularly noteworthy. The videotape describing the system (82:--) was made by recording the screen images with a standard camera. The SOAP system of software consists of a number of orbit-related software programs. The ability to rotate, translate, scale, provide different perspectives, and zoom are built into the hardware with the use of dials. The software takes advantage of this feature to provide dynamic views of many two-dimensional and three-dimensional space views. It provides for all of the implied orbit parameters of Table 10, and some additional capabilities described in the Appendix. The only display the author cannot completely verify that SOAP possesses is the BMD engagement display; but it does have the capability to display an ASAT engagement. It is used at the Air Force's Space Division where it was developed; the Air Force's Space Command by both operations and plans; and the Air Force Academy. SOAP is a powerful tool for conducting space-related research and education.

The display needs of the three audiences are varied, but those of the introductory and research audiences are somewhat similar. The displays needed for the CRES wargame are static. To simulate satellite motion for the other two audiences requires dynamic or animated (80:--) displays. We complete this chapter on displays with a look at some sample displays.

CANDIDATE DISPLAYS

Candidate displays have been presented in some of the figures used thus far in this report. This section will recapitulate the purpose of those displays, and provide a few more sample displays to illustrate points made earlier.

Status displays were described in Table 6, and Figures 7, 8 and 15. These are but a few of the possibilities, and any graphics system capable of moving displayed data around the screen should be able to accommodate a variety of formats for status displays.

A two-dimensional coverage plot was described in conjunction with Figure 6. A similar plot for a low orbiting satellite may look something like Figure 17. SOAP has a capability to dynamically update the coverage zone as the satellite moves along the

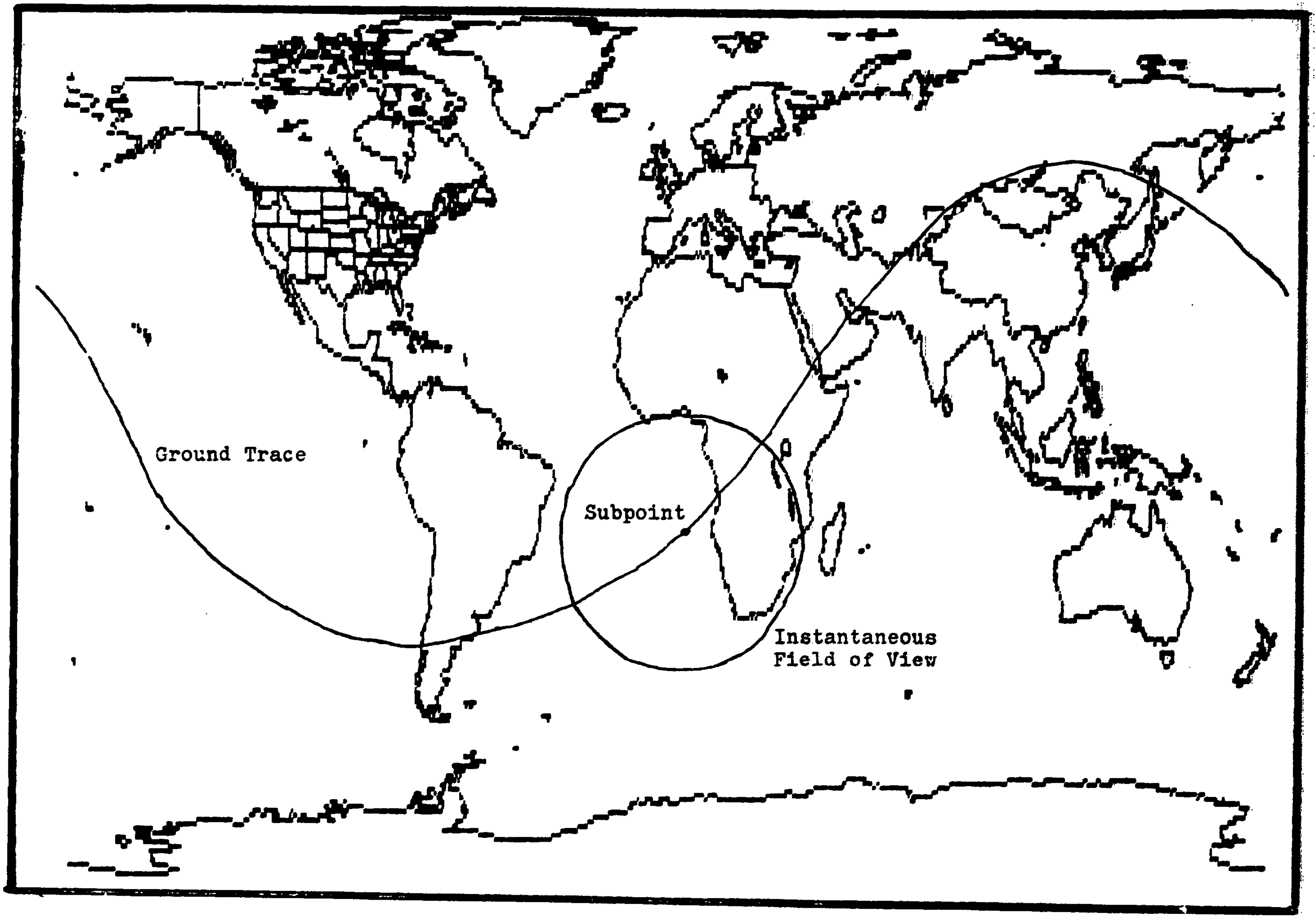

Figure 17 – LEO COVERAGE PLOT

ground trace projection (82:--). This plot may be useful when used in conjunction with the LEO satellite-to-earth view described earlier, or with a plot that shows the relationship to ground stations or sensors as in Figure 8.

SOAP also uses a coverage plot to indicate the motion of a satellite with respect to a ground station, i.e. an earth-to-satellite graph as in Figure 18. The circles represent elevations from the station, the radial lines represent azimuths. These may be of interest to researchers or to students interested in space support issues. Figure 13 describes an LEO two-dimensionally.

Three-dimensional perspective views of the earth and satellite are provided in Figure 1 on space zones, Figures 4 and 16 on ballistic plots, Figure 7 on geostationary satellite status, and Figure 12 on the orbit plane. A display of circular MEO's would be useful to illustrate the GPS constellation for example. Figure 19 displays these orbits. Because such a plot can become congested, SOAP has the ability to turn off the orbit traces with the press of a function key (82:--). Another medium earth orbit discussed earlier was the Molniya orbit. In order to summarize the different displays we have been talking about, four types of displays will be compared. The reader can then judge which display type is more informative. Table 11 lists the information necessary to describe an orbit. It is an alphanumeric listing of the orbital parameters. Figure 20 illustrates two different side views for a highly elliptical MEO.

Right Ascension of the Ascending Node (x) = 27 degrees
Inclination (i) = 63.4 degrees
Argument of perigee (w) = 270 degrees
Eccentricity (e) = .7
Semi-major axis (a) = 15,000nm
Epoch time at the ascending node (t) = 10:00:00Z 21 Jan 87

TABLE 11 - Keplerian Elements for an Orbit

The display is two-dimensional. Figure 5 described earlier, is a three-dimensional static view of the orbit. Finally, Figures 21 through 31 attempt to provide a satellite-to-earth view of the orbit for selected points in the orbit. The eleven viewing points are indicated on the left side of Figure 20. The eleven views simulate a dynamic view of the orbit. A truly dynamic view is obtained when the number of viewing points is increased and each display is replaced rapidly. Only dynamic displays give the viewer an idea of how things change in time. Three-dimensional dynamic displays are most helpful in visualizing satellite motion.

A number of HEO three-dimensional displays have already been illustrated. Literally hundreds of displays could be described. Each one could have some educational value to the audiences at

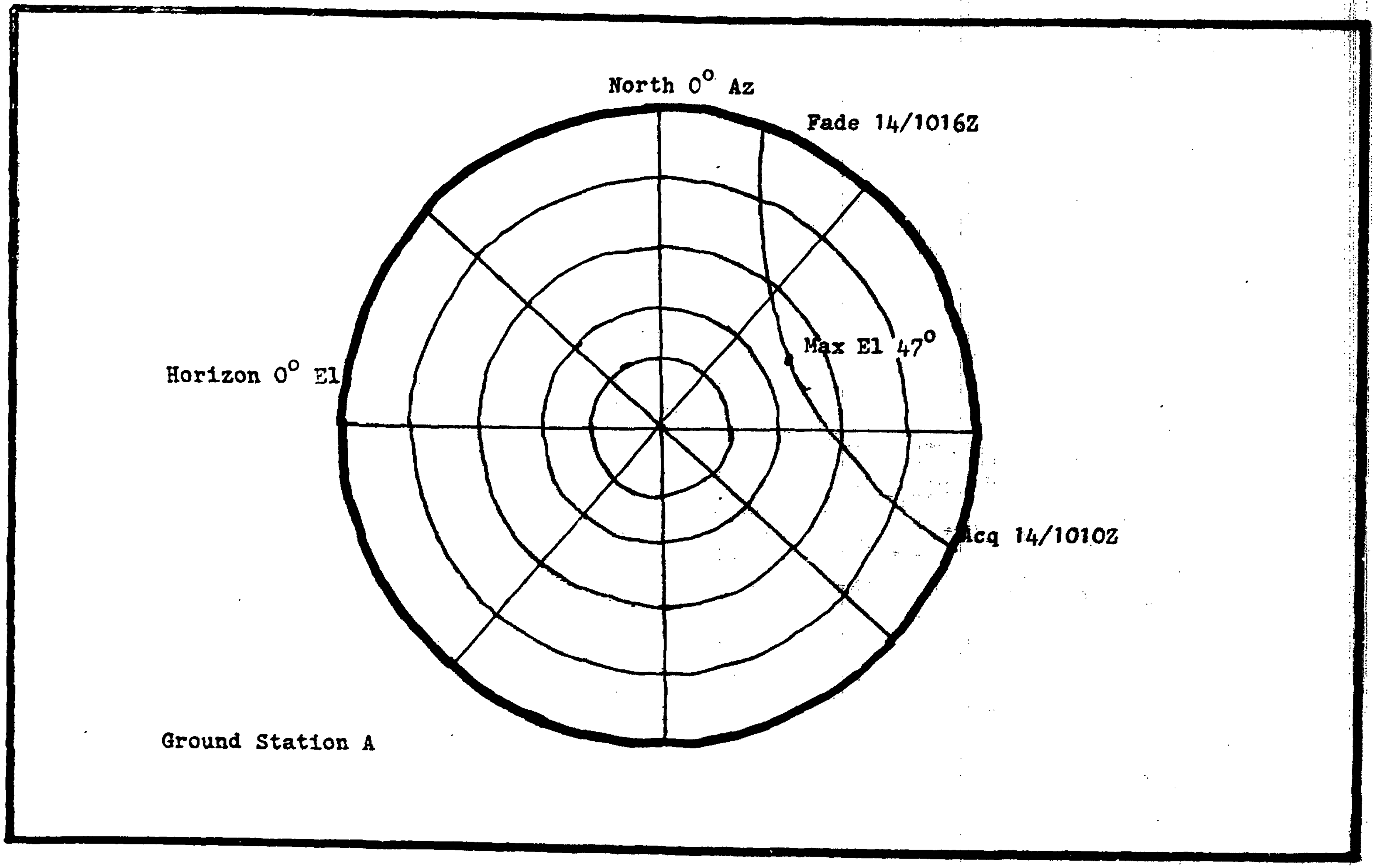

Figure 18 – EARTH-TO-SATELLITE PLOT

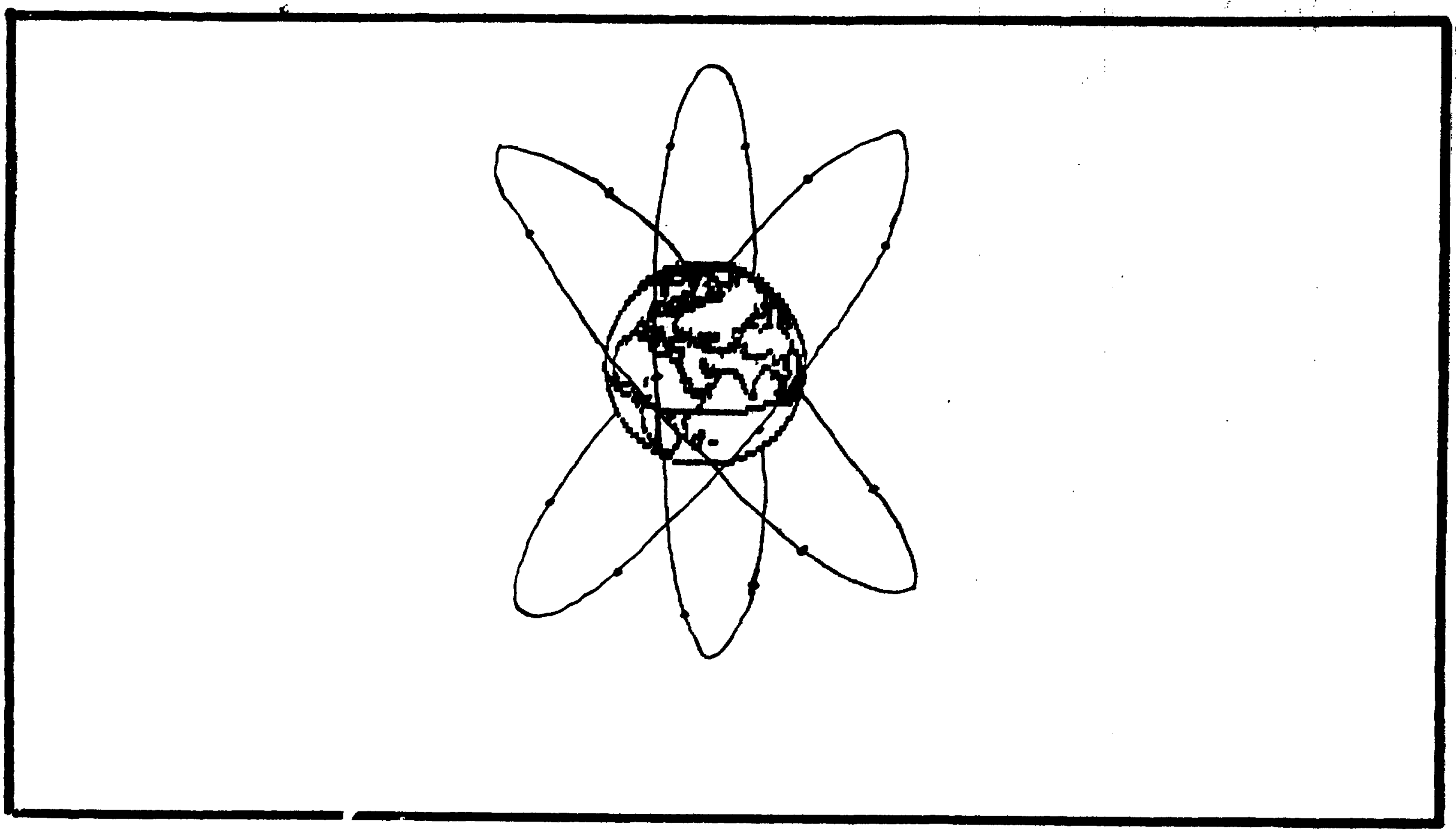

Figure 19 – MULTIPLE MEO SATELLITES

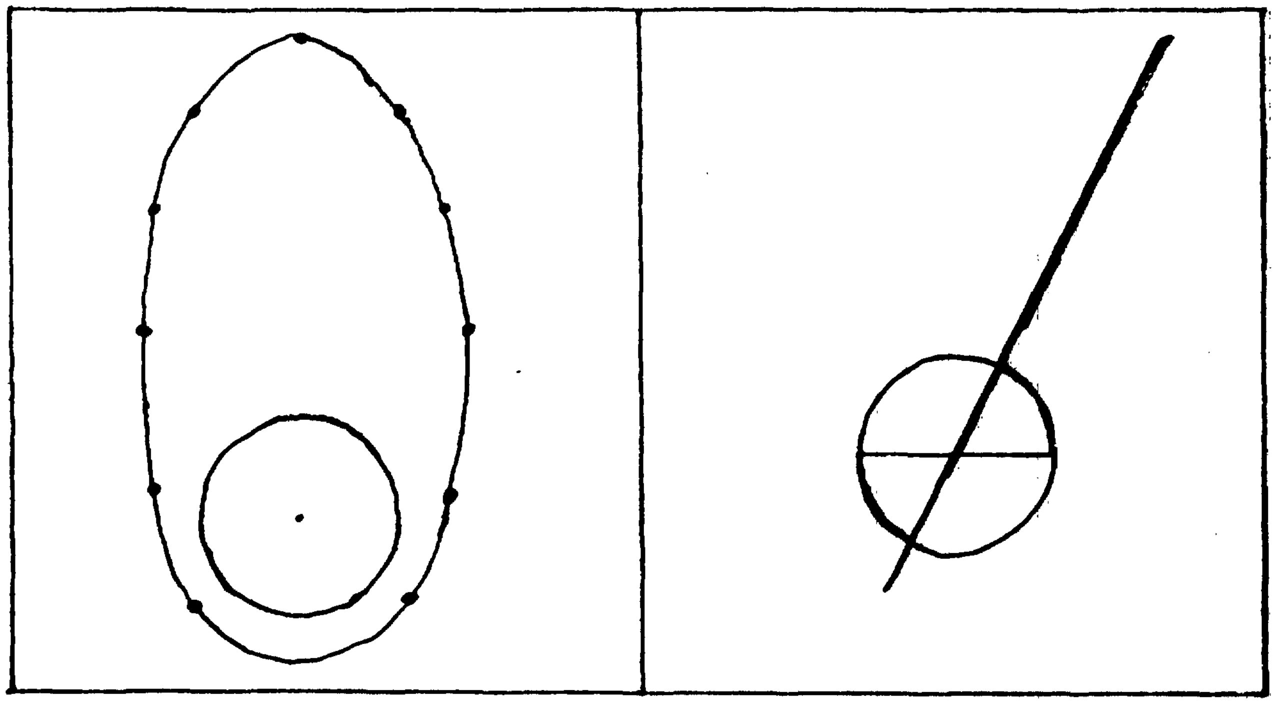

Figure 20 – AN ELLIPTICAL MEO

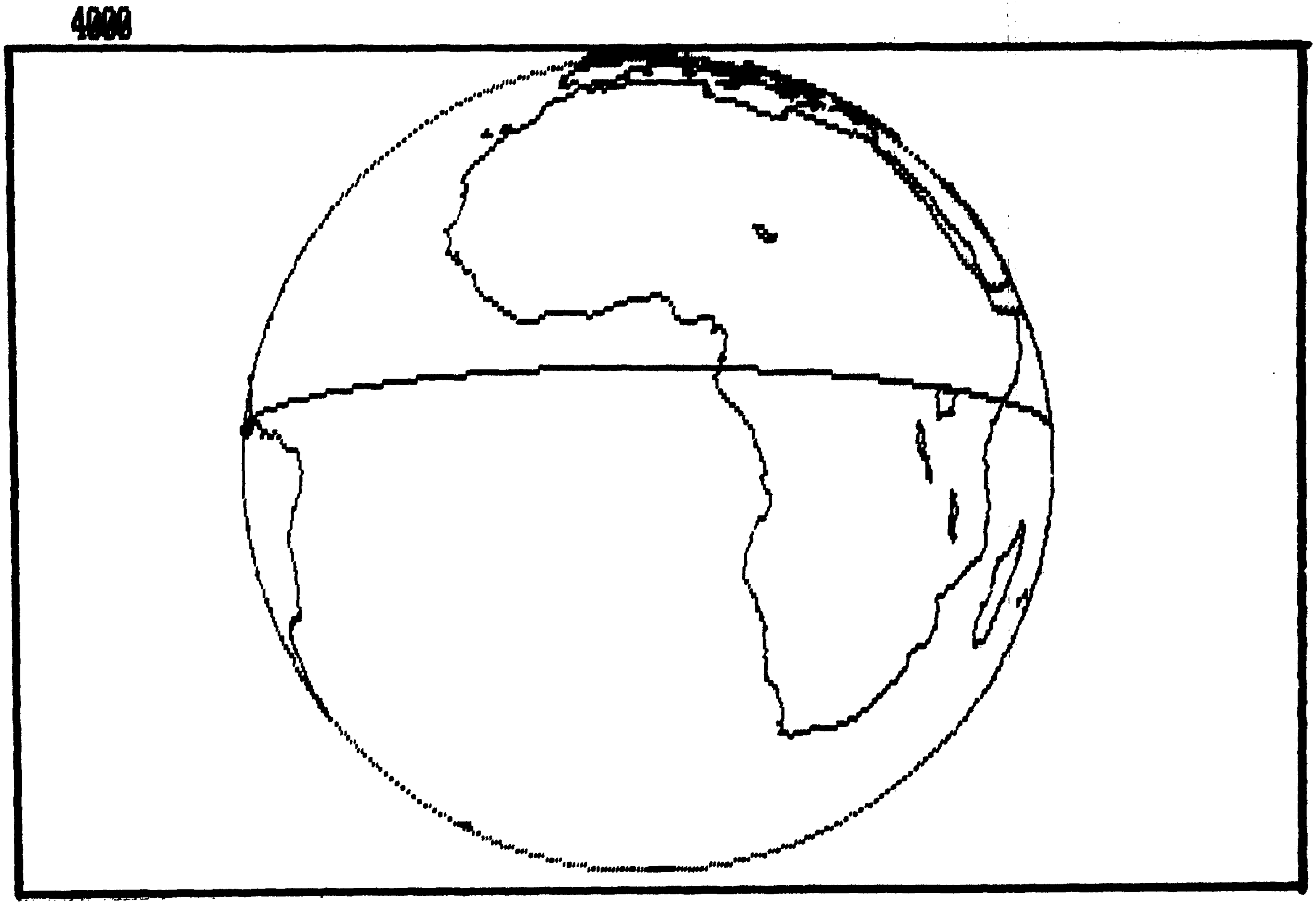

Figure 21 – SATELLITE–TO–EARTH VIEW #1

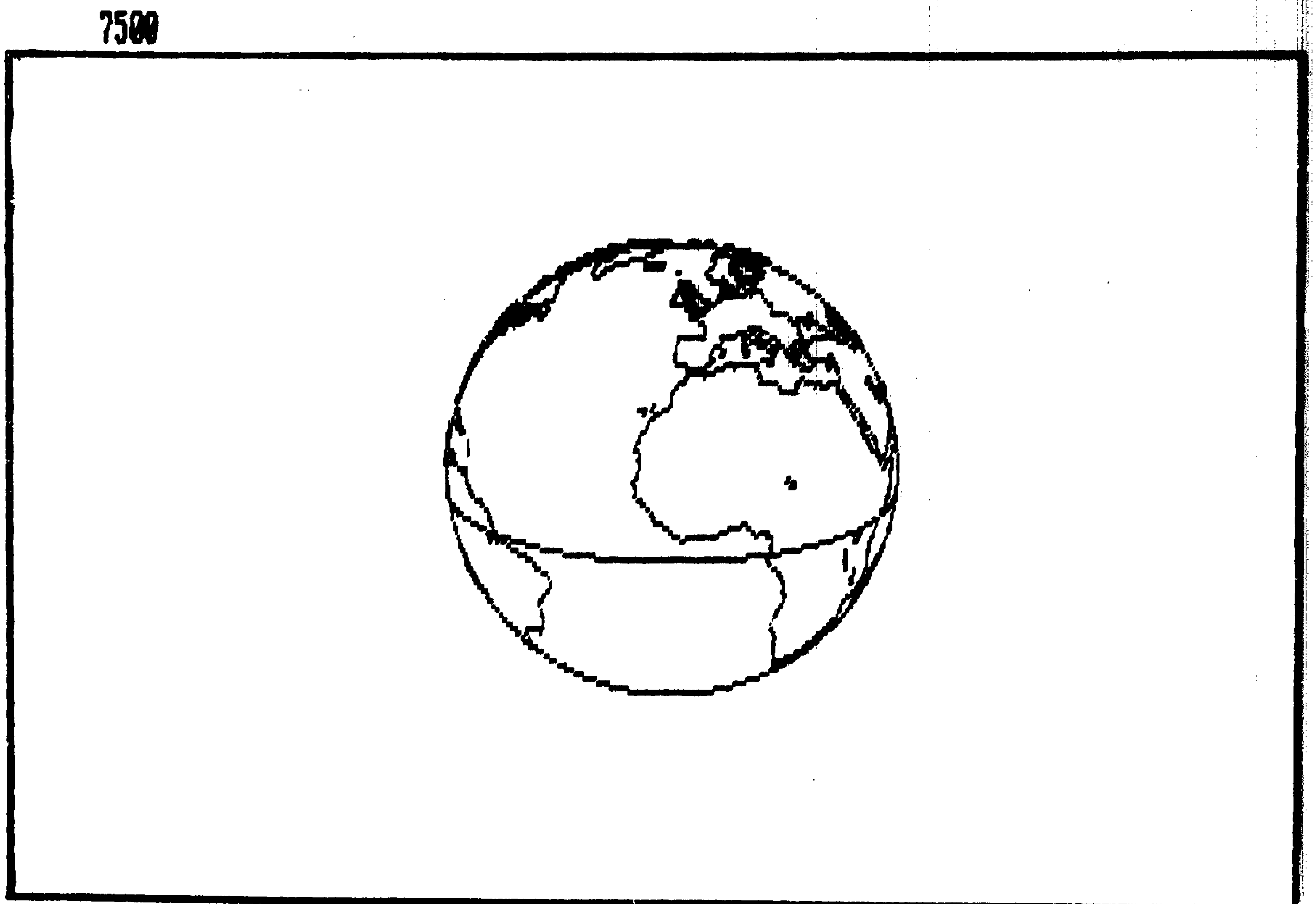

Figure 22 – SATELLITE-TO-EARTH VIEW #2

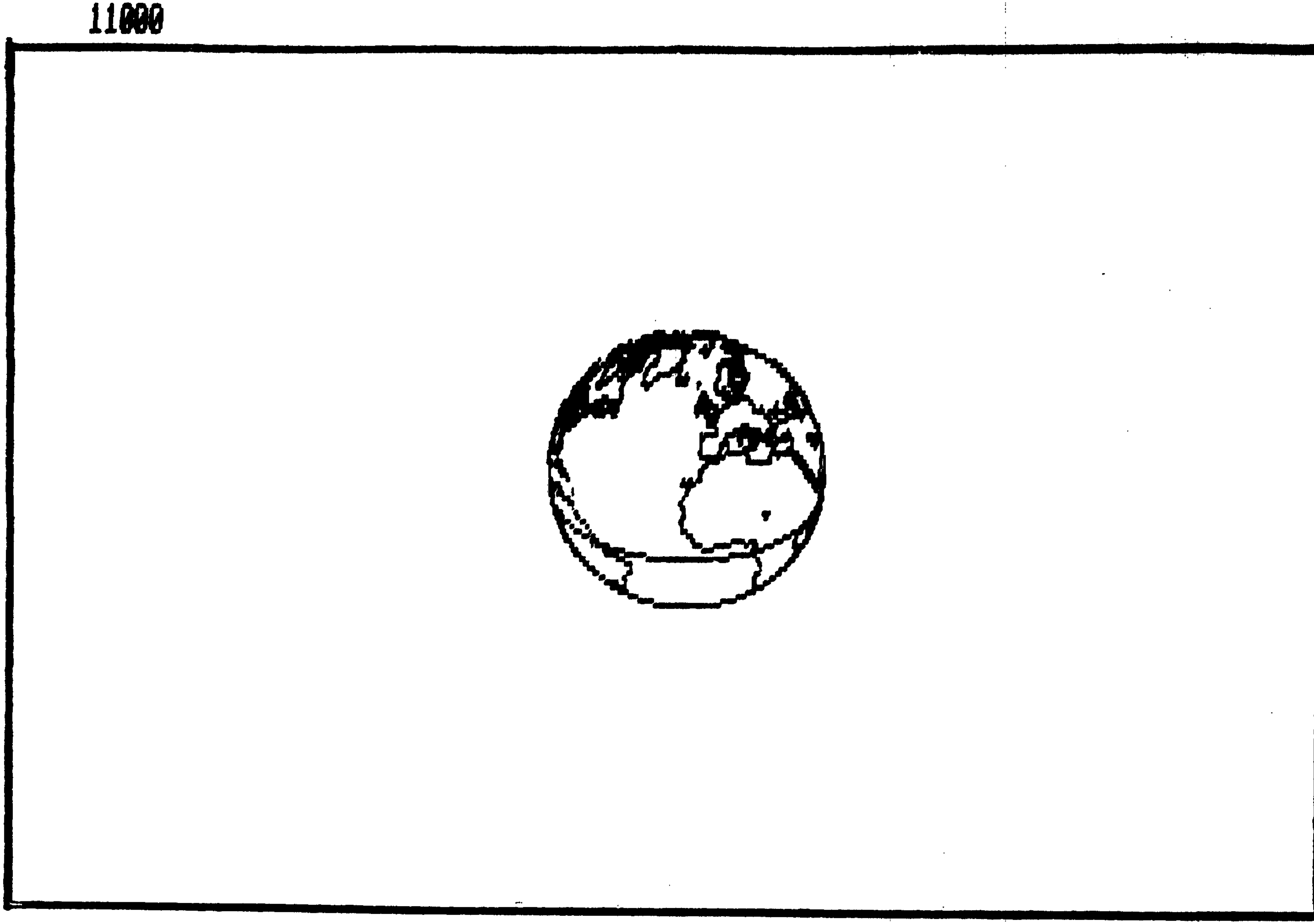

Figure 23 – SATELLITE–TO–EARTH VIEW #3

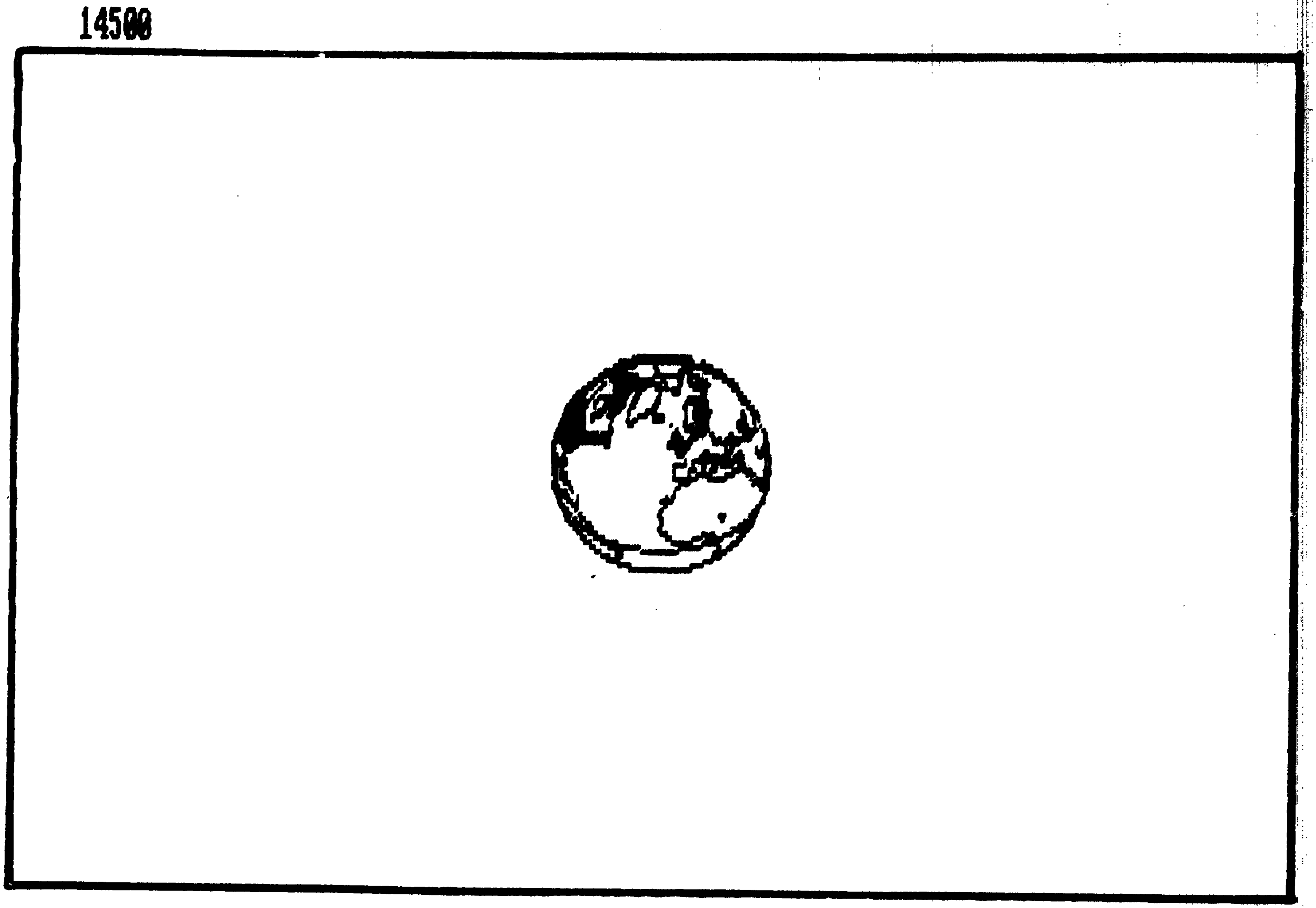

Figure 24 – SATELLITE–TO–EARTH VIEW #4

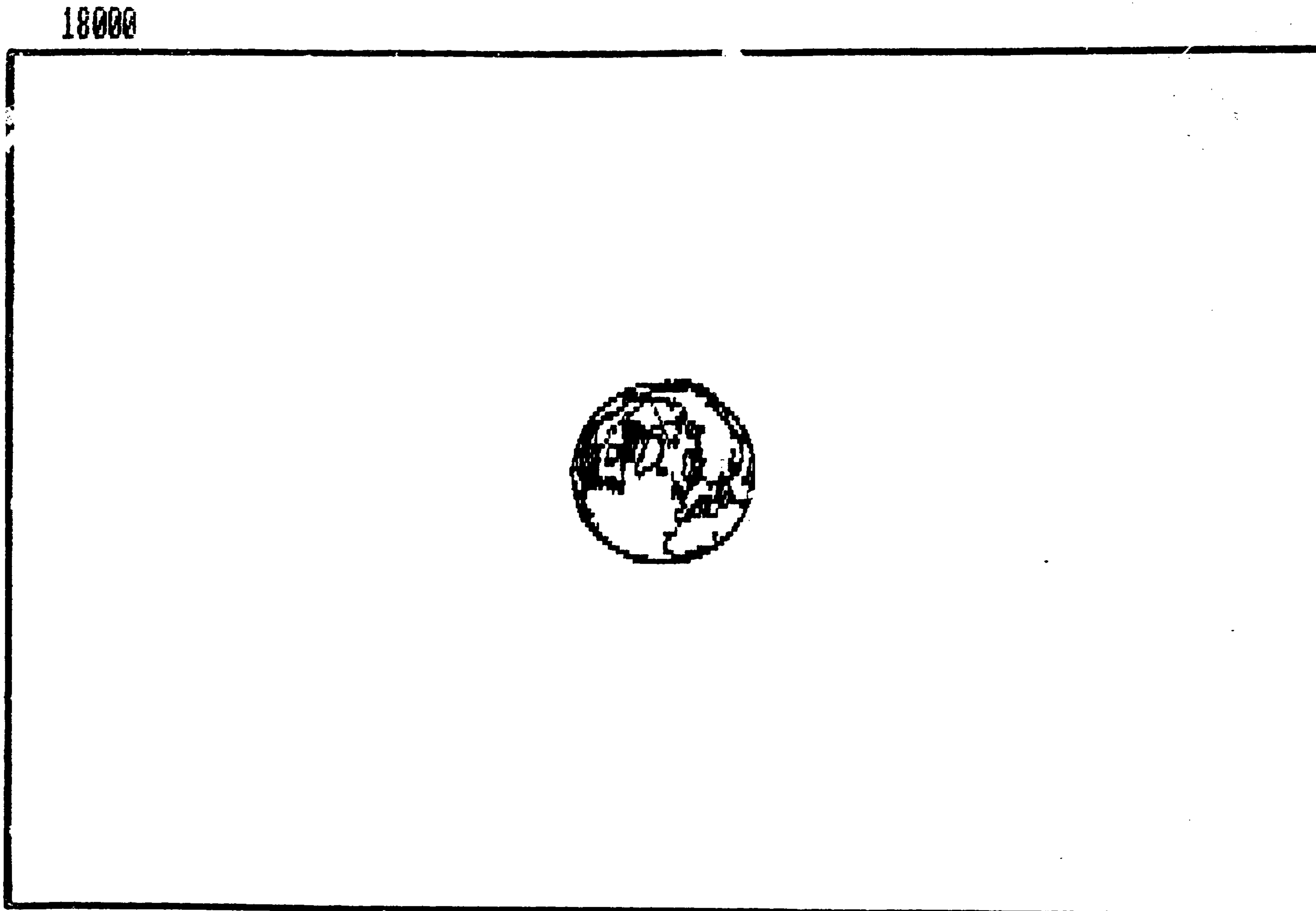

Figure 25 – SATELLITE–TO–EARTH VIEW #5

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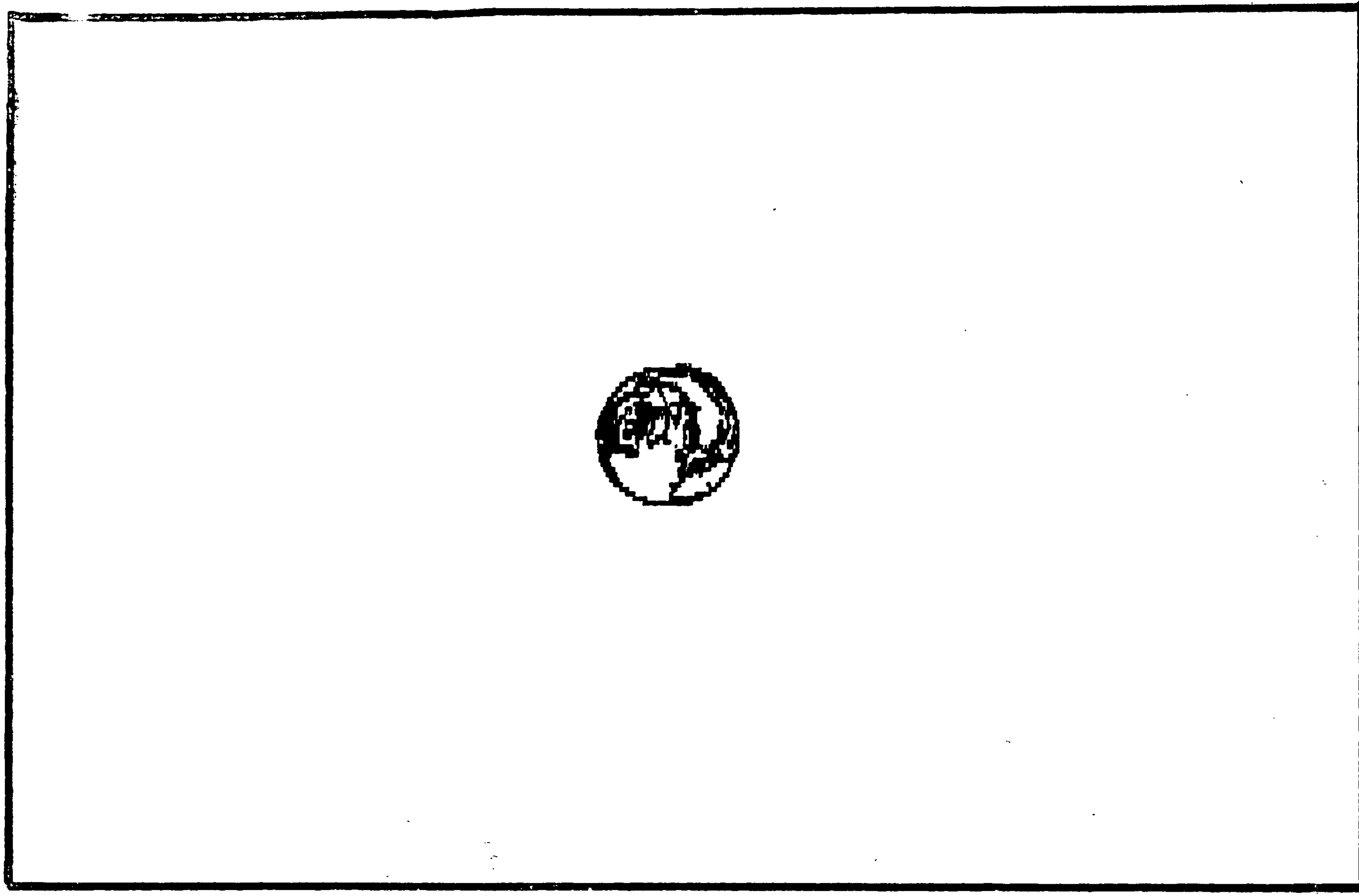

Figure 26 – SATELLITE–TO–EARTH VIEW #6

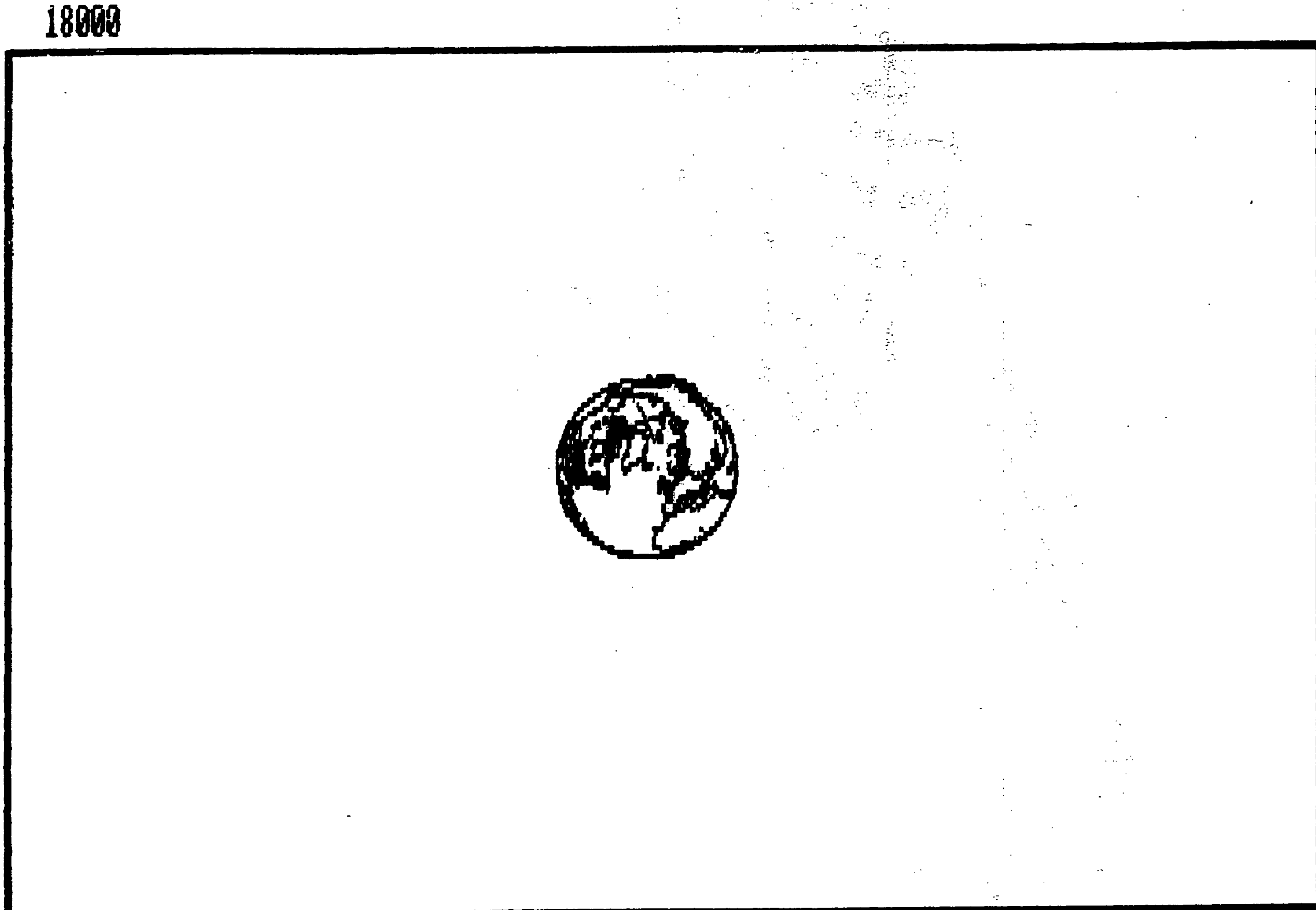

Figure 27 – SATELLITE-TO-EARTH VIEW #7

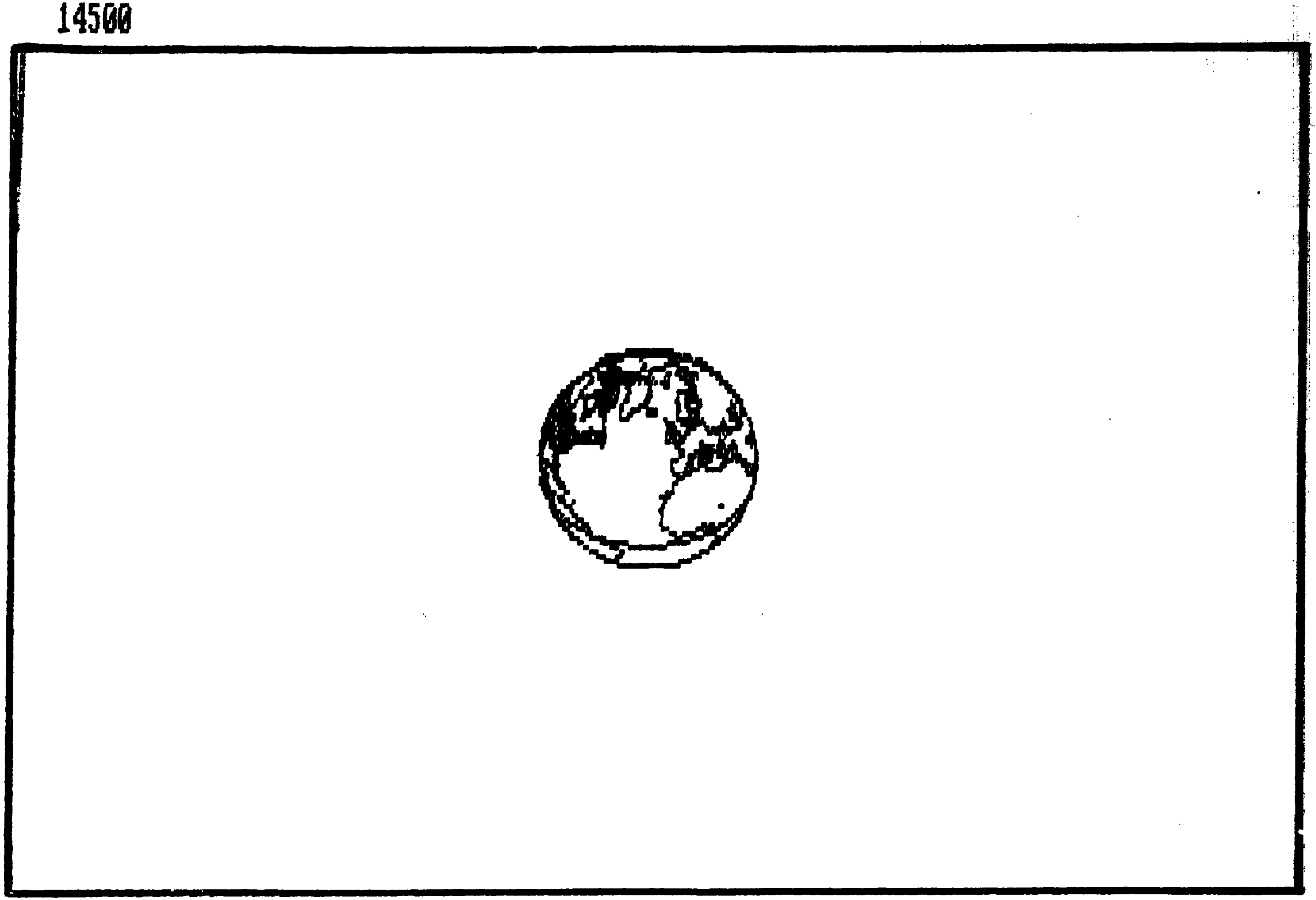

Figure 28 – SATELLITE-TO-EARTH VIEW #8

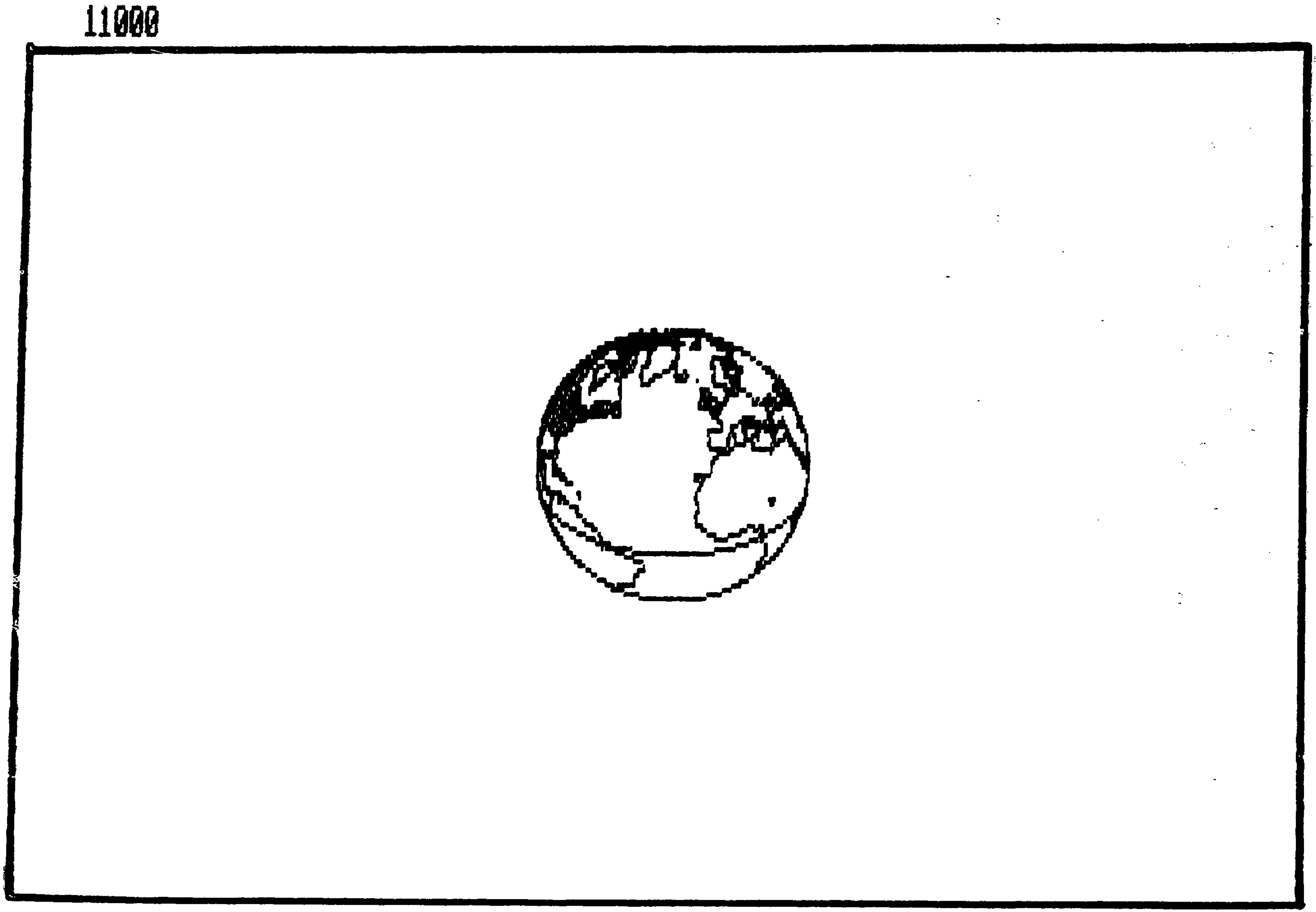

Figure 29 – SATELLITE-TO-EARTH VIEW #9

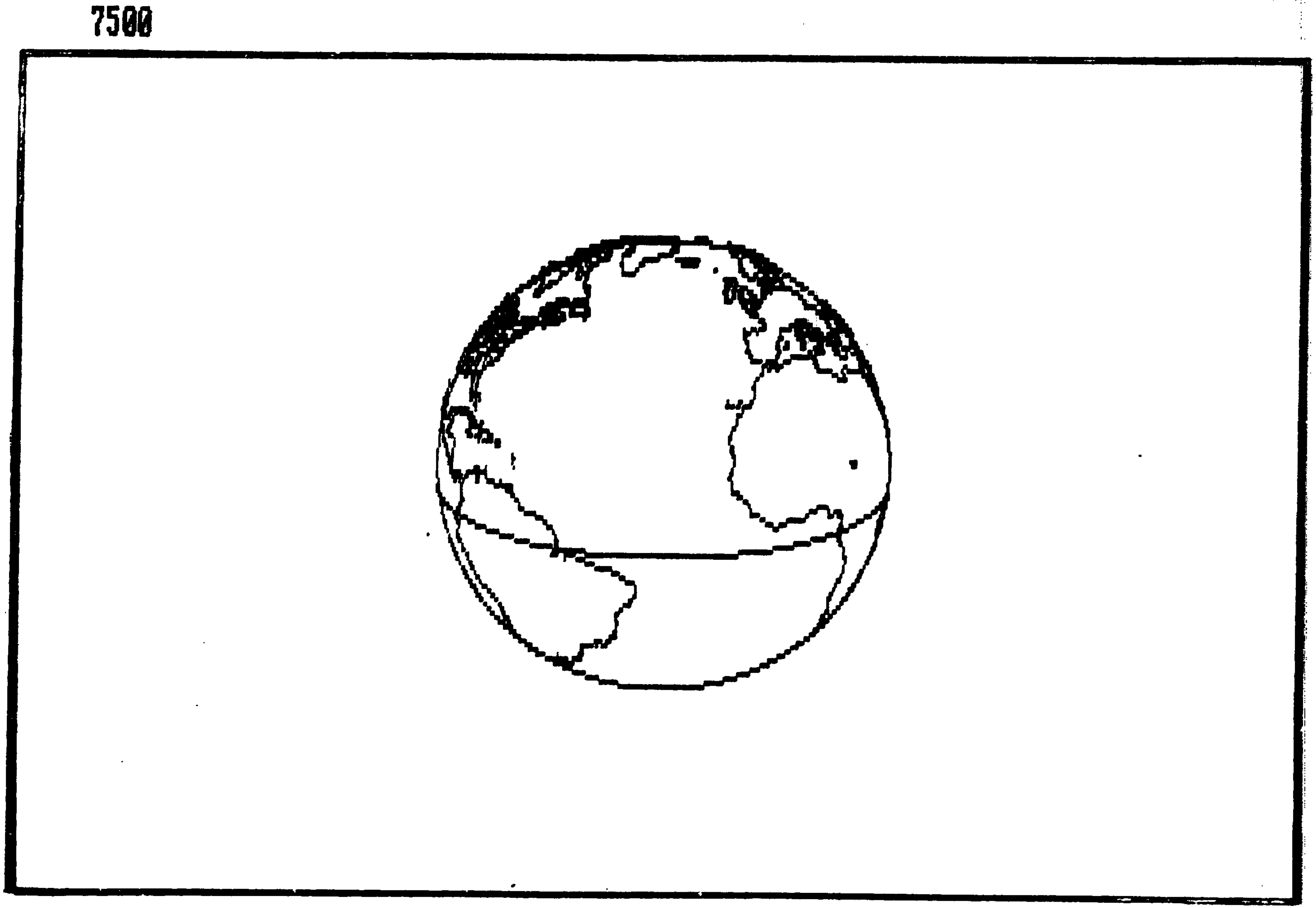

Figure 30 – SATELLITE–TO–EARTH VIEW #10

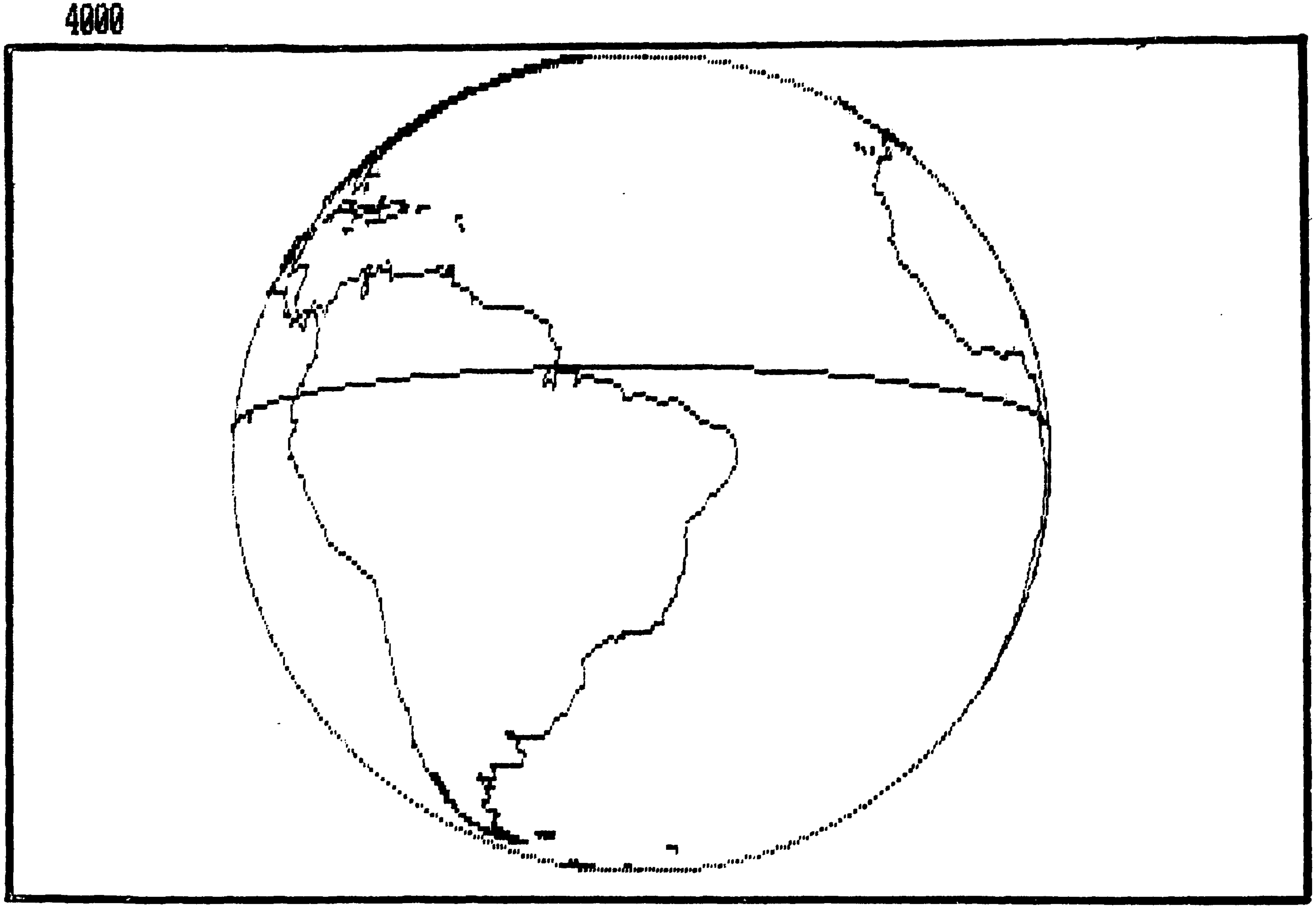

Figure 31 – SATELLITE–TO–EARTH VIEW #11

Air Unversity. The indicated displays are representative of the types of displays that would be used if they were available at Air University.

Displays can be more readily generated on computers than was the case five or ten years ago. Recent advances in computer graphics has led to the development of interactive computer graphics systems capable of supporting a large variety of applications. At Air University, the three audiences for space displays have different display needs; but both the introductory audience and the research audience would benefit from dynamic displays of satellite motion. A representative set of sample displays has been presented for future consideration.

CHAPTER FIVE

This study is concluded with a summary of the major topics. The three diverse areas of space, wargames and displays will be reviewed. The major conclusions reached will be described followed by a set of recommendations for future action.

SUMMARY

Space wargames have the potential to assist in the development of space strategy and doctrine. Only existing or near-term space capabilit'es have been considered in this study. The new Command Readiness Exercise System (CRES) at the Air Force Wargaming Center is the baseline system for consideration. The displays planned for use by this system are the basis for departure, but an additional display system may be needed.

Space is a harsh environment where vehicles operate differently than on earth. Their operating characteristics give them unique military advantages. For these reasons, space systems fulfill a variety of roles and missions with force enhancement missions predominating. However, space warfare may not be far away. With the development of ASAT systems and SDI BMD proposals, the likelihood of space warfare increases. Space activities are limited by both political and technical constraints, but technical constraints predominate. Military doctrines and strategies are needed to prepare for war in space, and only if the necessary tools are available will the research be done. Strategy studies will be required for defense in space, even if a comprehensive ban on weapons in space is agreed upon. As our technical abilities grow in space, our options increase; and thus the need to develop strategies and doctrines increases.

Wargames can assist in the development of strategies and doctrines. Wargames have been used throughout history to study military problems, and they are used extensively by a variety of US military organizations. There are many different categories of wargames, and many different types will eventually be available with the CRES system. A study group consisting of ACSC and AWC students this year has developed a plan for the introduction of space into the wargames to include the possible development of a space wargame. An approach has been suggested. Three audiences for space information were identified by the study group: the introductory audience, the wargaming audience, and the research audience. The information needs of each have been hypothesized.

Computer graphics capabilities have evolved over the past 30 years. Recent advances have resulted in the development of comprehensive interactive computer graphics systems. These systems are capable of reproducing realistic scenes as well as producing realistic looking animations. Alphanumerics, two-dimensional scenes, and three-dimensional scenes are all possible. The degree of modelling accuracy is dependent upon the number and sophistication of the techniques used to model three dimensions. However, a degree of visual modelling is available in personal computers. The Zenith Z-158 personal computer will be the terminal for the CRES wargaming system; and the Z-158 possesses a good graphics capability. Space systems can be used in CRES. Space modelling for the other two audiences, however, will require a new capability to depict the dynamic motion of the satellite. The Aerospace Corporation has developed a Satellite Orbit Analysis Package that will fulfill the space display needs. A number of display examples have been provided.

CONCLUSIONS

Space is a relatively new medium for military operations for which the different environment and operating characteristics require different doctrines and strategies. War in space is a distinct possibility, yet our doctrines and strategies are still evolving. Air University can contribute to space doctrine and strategy development, but only if the students and researchers have the right tools.

Wargames can and will contribute to the dissemination of space-related knowledge. A space wargame may help the development of doctrine and strategy. The display needs of the different audiences vary. Orbit simulation tools are needed to make space education and space-related research more efficient and creative (80:--). Recent advances in computer graphics technology permit the display of very accurate two-dimensional and three-dimensional scenes. Moreover, an orbit simulation system called SOAP has been developed for spacecraft design work. SOAP, if used at AU, would assist the introduction of space into the ACSC and AWC curricula; help in the development of a space wargame in conjunction with various manual wargames; and assist the serious student of space doctrine and strategy.

RECOMMENDATIONS

Given the needs of the three audiences described in Chapter 3, and the displays that are both available and needed as described in Chapter 4, the following recommendations are offered for future action.

First, it is recommended that a project be created, or software obtained, to view basic satellite scenes on the Z-158 computer. The wide spread use of this terminal in both the Wargaming Center and the seminars gives Air University the opportunity to make basic, three-dimensional, static displays available to a large audience of students. The static displays of this report are recommended for use.

Second, in phase three of the CRES development, the AFWC should incorporate models to simulate the effect of satellite systems as described in Chapter 3. The minimum areas for satellite modelling are described in Table 5, but all eleven areas should be modelled if possible.

Third, Air University should buy SOAP. This is not a statement on personal hygiene, but rather a practical recommendation designed to enhance the comprehension of students and researchers. SOAP could be used in conjunction with a lecturer to produce space-related videotapes (57:--). It would be useful for the development of a space-related wargame possibly in conjunction with a space elective course next year. It could be used in subsequent space elective courses as well. The hardware associated with the system is expensive (estimated at $65,000 (81:--)) when compared to personal computer costs; but one gets what one pays for. SOAP is a bargain, however, because in the author's opinion the software is worth $750,000 to $1,000,000; and it could be provided by Space Division free of charge. Finally, buying SOAP saves time. The space elective students could use this capability in conjunction with the manual games. To develop a similar capability will take time. The amount of programming time required would depend upon the degree of sophistication employed. A good benchmark for this might be achieved if the first recommendation is implemented. In the author's opinion, it would be more efficient to obtain a copy of SOAP. One copy should be obtained, and since the Air Force Wargaming Center also has a VAX computer, it would appear that SOAP should be located at the Wargaming Center.

The study concludes that space-related displays can help in both an educational and analytical context. The means to use the displays are available, and three recommendations are offered to improve the space-related wargaming and display capabilities of Air Unversity.

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APPENDICES

APPENDIX A

FIRST PRINCIPLES OF SPACE OPERATIONS

1. Earth satellites are "caught tight in the grip of gravity." The orbital paths they are constrained to follow, and the high velocities they must achieve, are completely explained by one influence--the force of gravity.

1a. The force of gravity is greater the closer a satellite is to the earth. Therefore, satellites in low orbits must travel at higher speed to escape gravity's inward pull.

2. Satellite orbits are very predictable and independent of satellite mass. If a satellite's position and velocity are known at a point in time, all orbital parameters and subsequent positions and velocities can be calculated. Following thrust termination, all satellites simply trace and retrace their prescribed circular or elliptical paths.

2a. There is a precise speed associated with every point in a satellite's orbit. A circular orbit is characterized by a specific, sontant velocity (which depends only on the radius of the orbit). An elliptical orbit is characterized by continuously varying velocity--maximum velocity is achieved at the lowest point of the orbit, and minimum velocity at the highest point.

3. Satellites possess energy by virtue of their velocity (kinetic energy) and distance from the center of the earth (potential energy). The sum of a satellite's kinetic and potential energy remains constant throughout its orbit.

3a. Satellites in elliptical o bits trade off their potential energy for kinetic energy in a manner analogous to an aircraft trading altitude for velocty. Kinetic energy is maximum at the lowest point of the orbit, and potential energy is maximum at the highest point of the orbit.

4. A satellite orbits in a plane that intersects the center of the earth, thus forming a great circle at its intersection with the earth's surface. However, the rotation of the earth under the satellite's orbit distorts the path the satellite traces on the earth's surface (its ground track).

5. Satellites, in general, continue in their orbits without degrading because of negligible friction in the vacuum of space. Satellites in very low orbits do experience some friction from the atmosphere which diminishes their energy and causes them to decay.

6. If an orbiting satellite produces thrust, its orbit must change. The accompanying change in velocity (magnitude and/or direction) precisely determines the satellite's new orbital parameters. Maneuvering to another desired orbit is accomplished by thrusting (changing velocity) at the right time and place.

MYTHS OF SPACEFLIGHT

MYTH #1: Once satellites achieve orbit around the earth, they are in a weightless environment.

REALITY: Earth orbiting satellites are caught tight in the grip of gravity. Satellites in the lowest earth orbits weigh approximately 95% of what they weigh on the earth's surface.

MYTH #2: Satellites remain in orbit because they are so high above the earth and because they are in a weightless environment.

REALITY: Satellites remain in orbit because they go so fast and are above the earth's atmosphere (negligible drag or friction).

MYTH #3: Satellites remain in orbit because centrifugal force (an outward force) precisely counters the pull of gravity, and thereby "holds" the satellite in orbit.

REALITY: There is no centrifugal force involved. The only force is gravity. Satellites continuously "fall" around the earth.

MYTH #4: Satellites in higher circular orbits travel at greater speeds.

REALITY: Just the opposite is true. Satellites in lower circular orbits travel at greater speed.

MYTH #5: Satellites can be stationed over any point on the earth and can be repositioned or moved to different orbits with relative ease.

REALITY: Satellites, in general, cannot hover over a point on the earth. Tremendous propulsive power may be required to change orbits due to the very high velocities involved.

MYTH #6: Satellite orbits are so complex and there are so many different kinds that they can only be described or explained via complex mathematics.

REALITY: There are only two kinds of satellite orbits: circular and elliptical. The paths satellites trace over the surface of the earth (ground tracks) are, seemingly, very complex and convince many that the orbits themselves are complex. Most satellite ground tracks are relatively easy to visualize once you understand that their shape is simply the result of the earth rotating under the satellite as it revolves around the earth.

MYTH #7: A space vehicle in a low earth orbit can be directly inserted into a high circular orbit by a single firing of its engine(s), if thrust is great enough.

REALITY: A satellite always returns to its point of thrust termination. Considering the characteristic short burn times for most conventional rocket engines, a space vehicle thrusting from low earth orbit would be in the same vicinity at thrust termination and would thus have to return to a low altitude for a portion of its orbit. The initial thruster firing could be used to achieve an intermediate elliptical orbit that reaches the desired final orbit only at its highest point. A second thruster firing, at the high point, would be required to circularize the orbit.

MYTH #8: Once a satellite achieves orbit, it will continue in orbit forever because there is no atmosphere (friction) in the vacuum of space to slow it down.

REALITY: For low orbiting satellites, residual atmosphere creates "drag" which slows a satellite down and will eventually cause it to reenter or "deorbit."

Student Handout for "Characteristics of Space Forces and the Space Medium," Seminar, 1 December 1986.

APPENDIX B

CRES Educational Objectives

Theater-Level Wargame allows students to plan, implement and analyze the outcomes of various air employment strategies. The overall educational objectives of the theater-level wargame are:

- To gain experience in theater-level air-combat decision-making.
- To learn to appreciate constraints on air operations.
- To understand the impact of close air support and battlefield air interdiction on ground combat.
- To learn air "mission-packaging" concepts.
- To appreciate constraints and uncertainties of realistic intelligence support.
- To learn how to prepare concise theater-level situation reports.
- To understand the limitations of the computer wargame.

Sub-Theater Level Wargame allows the players to devise the right "mix" of offense and defense in "mission packages" that accomplish their combat objectives while protecting their force.

Strategic Nuclear Exchange Exercise allows the student to:

- establish broad national guidance;
- determine force objectives;
- specify military options;
- develop force structure;
- generate weapon/target assignments;
- formulate defense strategy;
- change force status; and
- employ nuclear forces.

APPENDIX C

OVERVIEW OF THE SATELLITE ORBIT ANALYSIS PACKAGE (SOAP)

BASED ON A VIDEOTAPE PRODUCED BY

THE AEROSPACE CORPORATION, TRAINING AND EDUCATION DEPARTMENT
El Segundo, California

FOR THE GLOBAL POSITIONING SYSTEM PROGRAM - THERMAL ANALYSIS

MR. DAN BRYCE - SYSTEM DEVELOPER

Tape provided by: Mr. Dan Bryce
Mr. Paul Nystrom, and
Mr. Fred Pollack
1986

1. SOAP runs on an Evans and Sutherland PS300 Computer graphics display.
   - 19" high resolution, color vector refresh cathode ray tube (CRT)
   - Connected to a Digital Equipment Corporation VAX 11/785 for computations
   - 8 user programmable function dials
     - used to rotate, translate, scale and zoom in or out
   - 12 programmable function keys
     - can reset scale, etc.
   - Keyboard used

2. SOAP has a number of software subsystems. The first one considered is the Surface Display System (SUDS).
   - Displays spacecraft models for thermal analysis
   - Can distinguish surfaces that track sun
   - Color coding available for different surfaces

3. Define or Verify Ephemerides (DOVE): orbital parameters are verified and displayed.
   - 3D perspective provided of satellite orbit trace and the earth
     - Called overview earth
       - can rotate and translate to change perspective: top view, edge view, etc.
       - earth rotates; satellite motion represented by a moving asterisk
       - function key turns orbit trace on or off
       - depth for orbit trace provided via light intensity
       - user can zoom
   - Function key provides for solar shading model
     - shows umbra and penumbra of the earth's shadows
     - shows when satellite eclipses occur
   - Function key turns lattitude/longitude lines on and off the earth display
   - Function key turns continental boundaries on and off the earth display

- Can display the equatorial plane and the plane of the ecliptic (plane of the earth travelling around the sun)
- Dial can adjust argument of perigee
- Satellite-to-Earth Views
  - Function key turns ground traces on or off
  - For geostationary orbit: no apparent motion
  - Dial can change inclination
    - Ground trace forms a figure eight
- Can stop the display, change inclination, generate a new ground trace, and compare it to the first
- Can model a sensor on board satellite looking at the earth.
  - Dial enables user to change the half-cone look angle to the earth.
    - Increase the angle: the view expands
    - Decrease the angle: the view narrows around the ground trace
  - Dial enables one to zoom in or out on the earth view
  - Dynamic satellite-to-earth view
    - Very impressive for Molniya orbits - shows speed up at perigee, slow down at apogee
    - Possible for any orbit though
- Alphanumeric display indicates orbital parameters
  - Variety of coordinate frames available: Keplereir, Cartesian, etc.
  - Parameters change on the screen as dials are used
  - Unique time displays

4. Interactive Verification of Orbit Requirements (IVORY).
- Provides complex and detailed combinations of SUDS and DOVE
- Models or provides the following
  - Flexible inputs of orbit data
  - Tailored views
  - Numerical output
  - Orbit maneuvers
  - Sun Tracking
  - Eclipsing
  - Ground Traces
  - Sensor Tracking
- Six different predefined screens available
  - Overview Earth: similar to DOVE but asterisk is replaced by detailed satellite model from SUDS
    - Can zoom in on volumes like the earth's penumbra, or zoom in on the satellite - good for pointing modelling
    - Function key enables changing of perspective from the earth or satellite
  - Earth-to-Satellte view - can zoom up to the satellite from the earth
  - Sun-to-satellite view - shows rotation of satellite as it moves in orbit
  - Superimposed Views
    - Overview Earth view in center of screen

- Earth-to-Satellite view in upper left-hand corner
- Sun-to-Satellite view in upper right-hand corner
- Combine three displays - in three quadrants of the screen
- Combine four displays - in four quadrants of the screen

5. Configuration of Arbitrary Satellite Trajectories (COAST).
   - Displays multiple satellites in multiple orbits
   - Is still under developmen.
   - Overview earth shows multiple satellites moving in orbits
     - Function key turns orbit traces on or off
     - Can zoom in or out in a particular satellite
     - Can freeze, slow down or speed up time
     - Can color code satellites and traces
   - Can how two object engagement - ASAT trajectory compared to tellite orbit trace
     - Can zoom in on the intercept volume
     - Speed up, slow down or freeze time
     - Alphanumerics provide
       - Time since interceptor launch
       - Range to target
       - Speed to target
   - Can look at different perspectives on split screens
   - Provides dynamic two-dimensional ground trace and coverage plot
     - Multiple satellites can be color coded